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THE PASSING OF THE DIRECT-CONNECTED TURBINE FOR THE PROPULSION OF SHIPS.

By C. W. Dyson, Rear Admiral, U. S. Navy, Member.

In 1897 Sir Charles Parsons read before the British "Institution of Naval Architects" an article on "The Application of the Compound Steam Turbine to the Purpose of Marine Propulsion." During the ensuing discussion he made the following statement: "Down to fifteen knots screws should be driven direct; below that gearing would have to be used, and then the turbine would be applicable to all classes of ships." He looked with distrust on gearing; the small gearing might be made to work, but the application of large geared wheels was a questionable device.

The mountain peak from which Sir Charles viewed the future was not of sufficient height; his horizon was limited. It did not include either electric or hydraulic gears nor, what is of still more importance, did it include the present day requirements for powers of such magnitude that the fitting of direct

connected slow speed turbines for the development of these powers is prohibited by the enormous sizes of turbines which would be required and the practical difficulties which would be encountered in manufacturing and in fitting them on board ship.

In the few years since the first disclosure of the invention of mechanical reduction gear as installed on board the *Vespasian*, the application of the invention has extended from the modest power requirements of that vessel to the enormous demands for power of the British cruisers *Courageous* and class and the still higher powered *Hood*.

In about the same period of time electric propulsion has grown from the small initial installation in a Chicago fire tug to the 30,000 shaft horsepower of the *New Mexico*, with the contemplated 60,000 shaft horsepower in the latest designed battleships and 180,000 shaft horsepower in the battle cruisers.

Hydraulic reduction gear is a German invention and its development has been seriously interfered with by the Great War. Up to the breaking out of the war the largest installation made was that on the *Koenigen Louise*, a vessel which was sunk off the coast of England early in the struggle, while engaged in laying mines.

CONDITIONS PRODUCING NEED FOR "REDUCTION GEARS."

When the axial flow turbine first made its appearance in the field of marine propulsion, the turbine was connected directly to the line shafting driving the propellers. A necessary condition for turbine efficiency is that the revolving buckets or blades shall have a very high peripheral velocity. On the other hand, the requirements necessary to produce high propeller efficiency are low peripheral velocity of propeller blades, narrowness of blade widths and large propeller diameters; these latter requirements mean that, for high propeller efficiency when absorbing any given amount of power in a propeller, the revolutions of the propeller must be comparatively low.

It will be seen from the above that the requirements for turbine efficiency and for propeller efficiency are directly antagonistic.

The designers of the original turbine installations for marine propulsion deliberately neglected the question of propeller efficiency to such an extent that the whole problem of economy of propulsion was so stated to the public as to eliminate the question of the propeller from the problem and make it appear that the turbine economy was the only factor to consider in solving the problem for "economy of propulsion."

When the direct connected turbine is fitted in any vessel which operates through a wide range of speeds and whose ordinary operating speed and power are much below the designed full speed and full power, the loss in economy becomes much increased, as the steam consumption of the turbine per shaft horsepower delivered increases as the power being developed and the revolutions of the turbine decrease, slowly at first but increasing rapidly as the amount of these decreases in revolutions and power increases, until at very low percentages of power as compared with designed power the steam consumption becomes enormous.

This peculiarity of the turbine becomes of the utmost importance when considering the question of the type of machinery to adopt for propelling purposes in the cases of fighting ships. These vessels in addition to very high power and high speed requirements must also be capable of holding the sea for long periods of time without the necessity for refueling as frequency of refueling is a factor of vital military importance.

When merchant vessels are considered this question of decrease in economy of the turbine need not be considered, as such vessels steam at or near the designed speed at all times when in free route and the engines are therefore developing designed or close to designed power, so that the full power economy is being approximately realized in actual service under usual service conditions.

In the case of war vessels, therefore, it is necessary to provide such an arrangement of machinery as will render good economy not only at the designed speed and power but also at the small fraction of this power which is required for the low cruising speeds usually employed.

For both vessels of war and for merchant ships, however, any steps which can be taken to increase the general economy of propulsion are compulsory when means for doing this are existent and the object of this paper is to outline the steps which have been taken to date to increase the economy of propulsion of war vessels and the step common to both vessels of war and of commerce for the general betterment of this economy.

COMPARATIVE STEAM ECONOMIES OF TURBINES AND RECIPROCATING ENGINES.

In making a comparison of the economies of the above types of engines, as the typical Naval reciprocating engine the engines of the *Delaware* have been taken although they are not the best of their type, those of the *Texas* and *New York* and, of still later date, those of the *Oklahoma* surpassing them in economy under similar steam conditions.

As typical turbines, those of several destroyers, some with Curtis and some with Parsons turbines, have been taken, although by doing so the reciprocating engine is again handicapped as higher economies of the machine are realized in the small high-speed destroyer turbines than can be attained with the heavy battleship engines of the same type.

The reciprocating engines chosen have a ratio of H. P. to L. P. cylinder of about 1 to 9, a ratio of expansion of about 11, a steam pressure at the throttle of 265 pounds per gage and a vacuum in the condenser of 27 inches, the piston speed at designed power being 1,000 feet per minute.

The turbines operate with a steam pressure of 250 pounds per gage at the throttle and a vacuum of 28.5 inches of mercury.

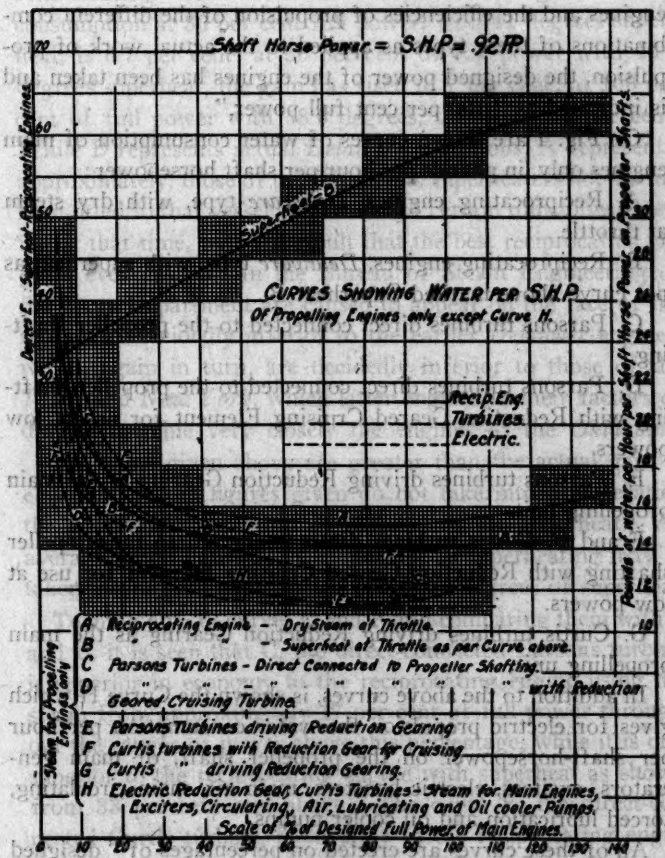

Shaft Horse Power = S.H.P. = .92 I.P.
Curves Showing Water per S.H.P.
Of Propelling Engines only except Curve H.
Recip. Eng.
Turbines.
Electric.
Pounds of water per Hour per Shaft Horse Power on Propeller Shafts.
Pounds of Steam per S.H.P. per hour for Propelling Engines only
A Reciprocating Engine – Dry Steam at Throttle.
B " " – Superheat at Throttle as per Curve above.
C Parsons Turbines – Direct Connected to Propeller Shafting.
D " " " " " " " with Reduction Geared Cruising Turbine.
E Parsons Turbines driving Reduction Gearing
F Curtis turbines with Reduction Gear for Cruising
G Curtis " driving Reduction Gearing.
H Electric Reduction Gear, Curtis Turbines – Steam for Main Engines, Exciters, Circulating, Air, Lubricating and Oil cooler Pumps.
Scale of % of Designed Full Power of Main Engines.
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140

FIG. 1.

BASIC POINT OF COMPARISON.

In order to compare the efficiencies of the various types of engines and the efficiencies of propulsion of the different combinations of these types as applied to the actual work of propulsion, the designed power of the engines has been taken and is indicated as "100 per cent full power."

On Fig. 1 are shown curves of water consumption of main engines only, in pounds per hour per shaft horsepower:

A. Reciprocating engines, *Delaware* type, with dry steam at throttle.

B. Reciprocating engines, *Delaware* type, with superheat as per curve above marked Superheat B.

C. Parsons turbines direct connected to the propeller shafting.

D. Parsons turbines direct connected to the propeller shafting with Reduction Geared Cruising Element for use at low powers.

E. Parsons turbines driving Reduction Gearing as the main propelling unit.

F and F. Curtis turbines direct connected to the propeller shafting with Reduction Geared Cruising Element for use at low powers.

G. Curtis turbines driving Reduction Gearing as the main propelling unit.

In addition to the above curves, is shown the Curve H which gives for electric propulsion the water consumption per hour per shaft-horsepower on the propeller shaft, of main generators, exciters, electric boosters, main air, main circulating, forced lubrication and oil cooler pumps.

All of these curves are erected on percentages of "designed full power of the engines" as abscissas while the ordinates are "pounds of water per shaft horsepower on the propeller shafts" and degrees, Fahr., of superheat.

By examination of curves A and B it will be found that where superheat is applied, even in such small amounts as

shown by the superheat curve given, the advantage derived is of such great amount as to be worthy of the most serious consideration. Thus for the case in question, the gain in water consumption at 30 per cent full power, with 41 degrees superheat, is 6.7 per cent; at 50 per cent of full power with 46.3 degrees superheat, the gain has risen to 7 per cent; at 100 per cent of full power with 58.6 degrees, the gain is 8 per cent. While B represents actual *Delaware* conditions, A represents, approximately, those of the *Oklahoma*, superheaters not having been fitted to that vessel on account of certain difficulties existing at that time, with the result that the best reciprocating engines ever designed in the Bureau of Steam Engineering of the Navy Department are caused to appear on the face of the returns as decidedly inferior to the earlier *Delaware* engines, which, again in turn, are decidedly inferior to those of the *Texas* and *New York*, which latter engines in their factors of design resemble very closely the engines of the *Oklahoma*.

The gains given above are greater than the actual gain in economy, as the figures given do not take into consideration the additional heat required to produce the superheat. An average rough figure for the gain due to superheating may be taken as one per cent gain for every ten degrees of superheat.

Turning now to curves C and F and comparing them with A and B, it is seen that C, the direct-connected Parsons turbine, is superior in economy to the reciprocating engine using dry steam from approximately 17 per cent of full power throughout the ranges of power above this percentage, while it is only superior to the reciprocating engine with superheat as shown, from 33 per cent and above. The curve F, the direct-connected Curtis turbine, is superior to the reciprocating engine with dry steam from 33 per cent of full power and upward, while it is superior to that engine with superheat as shown, in the ranges of power above 80 per cent of full power. Attention is called to the character of the curves A, B, C and F. A and B both show a decrease in water consumption more or

less rapid until 80 per cent of full power is being developed. At this point the water consumption gradually increases due to the rapid increase of back pressure in the L. P. cylinders caused by the restricted area of the exhaust ports. C and F show no such changes but the water consumption per S. H. P. is decreasing rapidly throughout the entire range of powers given, indicating an excess of area for steam flow through the turbines, and this decrease would continue so long as the peripheral bucket speed increased and the areas for steam flow could take care of the amount of steam flowing without a banking up of resistance sufficient to require an undue expenditure of pressure to overcome it.

MEANS ADOPTED TO OBTAIN INCREASE IN ECONOMY AT LOW FRACTIONS OF DESIGNED FULL POWER.

Inspection of curves A, B, C and F show that with direct connected turbines there are two remedies which can be applied to reduce the steam expenditures at low fractions of designed power, without introducing an additional propelling element to be used at such powers. These remedies are:

1. The use of superheated steam.

2. By designing the turbines so that the curves of steam consumption C and F will be moved bodily to the left. This would require much higher steam and bucket velocities at the 100 per cent power design point than were used with the turbines from which these curves were derived.

The increase in economy of the engines due to the use of superheat is shown on Fig. 1, curves A and B, where with only 58.6 degrees Fahr. superheat at the 100 per cent design point, the decrease in steam consumption due to the superheat amounts to 7 + per cent, while at 10 per cent of the designed power, the gain, with only 34.5 degrees superheat, amounts to 8¾ per cent.

The gains obtained by resorting to the second remedy are shown by the comparison of curve G with curve F for Curtis

turbines, and of curve E with curve C for Parsons turbines. In the case of the Curtis turbine, in applying the second remedy, gain in economy at the 100 per cent point has been deliberately sacrificed in order to increase the gain at the lower fractions of power so that while at the 100 per cent point the steam consumptions of F and G are rising, it is seen that the maximum gain shown by G occurs at 75 per cent of full power, this gain amounting to about 20 per cent, while at 10 per cent of designed full power it amounts to approximately 35 per cent. G, however, considering the engine economies only, is superior to A and B throughout all practical ranges.

Curves F and G are, however, not the best that the Curtis turbine can deliver as will be seen by examination of curve H, Fig. 1. This curve shows the performance of a Curtis turbine used for driving the generator of an electric drive installation. The bucket speeds averaged about 5 per cent higher than those of curve G, while the superheat ranged from about 15 degrees Fahr., at 10 per cent of designed power to 24 degrees Fahr., at designed power. The water consumptions of curve H, however, in addition to the consumption for the main turbine, include the consumptions for the following auxiliaries, of which only the first two given are a legitimate charge against the engines:

1. Exciters.
2. Electric boosters.
3. Main circulating pumps.
4. Main air pumps.
5. Lubricating pumps.
6. Oil cooler pumps.

Auxiliaries 1 and 2 are extra auxiliaries required for electric propulsion, while the remainder are common to all systems of propulsions although 6 is not usually fitted in cases A and B.

Turning now to the Parsons turbine performances as shown by curves C and E, the latter curve shows a water consumption at full power about 9 per cent lower than C, nearly 7 per cent

better than G, approximately 21 per cent better than B and nearly 27 per cent superior to A. At the points of maximum economy for G, B and A, the superiorities of E in economy are approximately 15 per cent, 20 per cent and 26 per cent respectively. At 10 per cent of designed power the superiorities of E over B and A are approximately 7 and 11 per cent in the order given.

Correcting curve H for the steam required for auxiliaries 3, 4, 5 and 6, would cause it to drop down more nearly to the position of E at the higher percentages, causing it to cross E at a still higher value of percentage of full power than shown, which is about 29 per cent, below which value electric propulsion turbines are far superior to either the marine Curtis or the Parsons turbines in steam economy, while the application of high degrees of superheat, which can be safely used with this turbine but cannot be used with the Parsons turbine, unless impulse first stage is fitted, would put the electric propulsion as well as the marine Curtis turbines far in the lead in economy.

APPEARANCE OF CRUISING ELEMENTS.

In the first steps taken to improve the economy of propulsion at the lower percentages of power and in some cases, throughout the range of powers up to full power, neither remedies 1 nor 2 were resorted to. Instead of these remedies, that of fitting other steam driven machines for use throughout a limited range of the lower percentages of power, these auxiliary units being either disconnected at, or running idle in a vacuum throughout, the higher ranges, was adopted. These variations of auxiliary units, classed as remedy

1. Fitting of Cruising Elements—were adopted in the following order:

a. Adopting of cruising turbines; these usually consisted of a H. P. and an I. P. cruising turbine with their steam areas and bucket speeds more nearly adjusted to the economy re-

quirements for the speeds and powers at which they were to be used than were those of the main turbines at these same powers. In the case of Curtis turbines, these auxiliary turbines were not used but in place of them special cruising nozzles were fitted to the main turbine. The H. P. cruising turbine or cruising nozzles were, in the case of a 21 knot battleship, kept in operation up to about 15 knots; the I. P. cruising turbine or nozzles kept in up to about 19 knots; from 19 knots on the main turbines or main nozzles only were used, the cruising turbines turning idly in a vacuum. The cruising turbines when in operation exhausted to the main H. P. turbine.

b. Adoption of reciprocating engines for cruising in place of cruising turbines; such a plan was first tried in some destroyers of the British Navy, but the mistake was made of designing these engines for such a low power and speed that they were practically useless. Later when adopted in the U. S. Navy, they were designed to carry the destroyer up to fifteen knots and when properly designed were very successful.

c. Combination of reciprocating engines and L. P. turbines for increase in economy throughout the entire range of designed power; this combination was first adopted in some merchant vessels where the power was arranged on three shafts, the outboard shafts each being driven by a triple expansion reciprocating engine with both engines exhausting to one L. P. turbine on the center shaft. The combination was very successful but as designed was not suitable for naval work where the ordinary cruising speeds are far below the maximum speed of the ship. For such a case it is necessary to use the H. P. and I. P. cylinders only of a triple expansion engine on one shaft, these highly efficient cylinders taking the place of the comparatively inefficient H. P. turbine, while the inefficient L. P. cylinder is replaced by the highly efficient L. P. turbine. If the beam of the ship is sufficient to carry propellers of diameter enough for high propulsive efficiency, the arrangement as outlined should give economies of propulsion in excess of those given by either reciprocating or direct connected tur-

bine engine installations except at such fractions of designed speed and power where the L. P. turbine becomes a drag on the system. So long, however, as the L. P. turbine is developing power, the combination will be much more economical in steam consumption than either of the direct connected installations, reciprocating or turbine, operating singly. This combination as outlined was proposed for installation in two of the U. S. dreadnaughts contracted for in 1909, and bids were invited for such installations, but circumstances were such at that time that it was considered better not to make the experiment. Several years later, however, the French installed such an arrangement in several of their new vessels.

d. Adoption of cruising turbines with reduction gear; trials of the *Vespasian* and of the U. S. S. *Neptune* having demonstrated the reliability and efficiency of reduction gears when properly designed, built and installed, and when absorbing comparatively low powers, such gears were immediately turned to as the solution when the cruising radius speed of U. S. destroyers was raised from 15 knots to 20 knots, this latter speed requiring entirely too high a speed of revolution for reliability if reciprocating engines were used. As the direct connected cruising turbines had given way to the much more efficient cruising reciprocating engine, so the latter was forced to make its exit and the unit of cruising turbines transmitting their power to the main shafts through reduction gears made its appearance.

No data being available which gives the water consumptions for the propelling engines only, when fitted with direct connected cruising reciprocating or turbine engines, the following data which includes the water consumption for auxiliary machinery also, and which has been obtained from the trial reports of similar vessels is given in order that a good idea of the relative economies of direct connected turbines in combination with cruising elements as outlined in *a*, *b* and *d* may be obtained:

	Direct connected turbines with	Fraction of Designed Power	Pounds of Water per S. H. P. per hour for all purposes
a.	Direct connected cruising turbines	.047	35.486
b.	Direct connected cruising recip. engines.....	.04	29.828
d.	Cruising turbines connected through reduction gear...	.04	34.543

Inspection of the above table indicates an enormous gain in economy of steam when the change from *a* to *b* was made but that a decided loss occurred when the change from *b* to *d* occurred. As already stated, however, in order to obtain reliability of machinery at high cruising revolutions the change was necessary even though the loss in economy came with it.

Data of performances of the *d* combination are available and such performances, that is, the pounds of water per shaft horsepower per hour, excluding auxiliaries, are shown on Fig. 1, where the short curve F-F at the left of the figure gives the water consumption for Curtis turbines fitted with *d* for cruising while the curve D is the same for Parsons turbines fitted with the same type of cruising element. The Curtis combination is seen to have the advantage in economy below 9 per cent of full power. At 9 per cent of full power the water consumptions of the two types are each 17.2 pounds while at 5 per cent, the Curtis turbine combination requires 19.8 pounds and the Parsons 22.4 pounds; but both are inferior in economy to H, electric, at the lower fractions of power while the Curtis marine combination as given by the combination of the two curves F-F, F-F is much inferior throughout the entire range of powers. As for the Parsons E curve, D shows more economy throughout the range where used, while the Curtis combination, F-F is only superior below 14 per cent of designed power.

To summarize the steam economies of the different types, the following table showing the standing in the order of economy is given:

Type	Percentage of Designed Power		
	5	30	Full
Reciprocating Engine—Dry Steam	7	6	7
Reciprocating Engine—Superheat	6	4	6
Parsons Turbines—D. C.	8	5	4
Parsons Turbines—D. C. with G. C. E.	4	...	...
Parsons Turbines—Reduction Gear	5	2	1
Curtis Turbines —D. C.	9	7	5
Curtis Turbines —D. C. with G. C. E.	3	...	...
Curtis Turbines —Reduction Gear	2	3	3
Electric Propulsion	1	1	2

The above results show the relative economy standing of the propelling engines considered as machines only and take no account of propulsive efficiencies of propellers that can be realized nor, therefore, of the combined economies of propulsion of engines and propellers. This point of view will now be considered.

ECONOMY OF PROPULSION, ENGINES AND PROPELLERS.

PROPULSIVE EFFICIENCY OF PROPELLERS.

In applying the foregoing types of machinery to the actual work of propulsion, a vessel of the Dreadnaught type has been chosen, while the propeller performances of the *Delaware*, *Pennsylvania* and *Utah* have been taken as representing the best that may be expected under the three conditions considered, namely, the *Delaware* at 125 revolutions, *Pennsylvania* at 214 revolutions and the *Utah* at 310 revolutions. The standard vessel used in the comparison has an effective (tow-rope) horsepower and speed curve as shown on Fig. 3. The effective horsepower for 21.3 knots, the designed speed is 15,250.

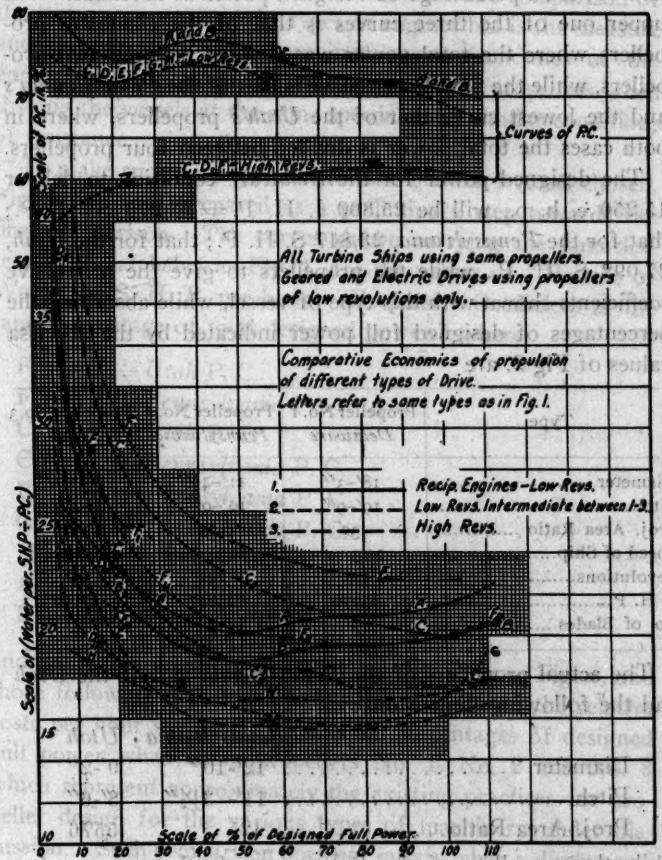

Curves of P.C.
All Turbine Ships using same propellers.
Geared and Electric Drives using propellers of low revolutions only.
Comparative Economics of propulsion of different types of Drive.
Letters refer to some types as in Fig. 1.
1. Recip. Engines – Low Revs.
2. Low Revs. Intermediate between 1-3.
3. High Revs.
Scale of (Water per S.H.P.÷P.C.)
Scale of % of Designed Full Power.
0 10 20 30 40 50 60 70 80 90 100 110

FIG. 2.

On Fig. 2 are shown three curves of propulsive coefficients laid down on percentage of designed power as abscissas. The upper one of the three curves is that of the *Delaware* propellers where the total power was divided between two propellers, while the next lower curve is that of the *Pennsylvania's* and the lowest curve that of the *Utah's* propellers, where in both cases the total power is divided between four propellers.

The designed power for the *Delaware* condition to deliver 15,250 e. h. p., will be 25,300 I. H. P. = 23,276 S. H. P.; that for the *Pennsylvania*, 23,847 S. H. P.; that for the *Utah*, 27,092 S. H. P., while the propellers to give the propulsive coefficients shown with this type of vessel, while absorbing the percentages of designed full power indicated by the abscissa values of Fig 2, are

Type	Propeller No. 1 *Delaware*	Propeller No. 2 *Pennsylvania*	Propeller No. 3 *Utah*
Diameter	18′-3″	11′-4½″	8′-11½″
Pitch	19′-9″	10′-0″	8′-4″
Proj. Area Ratio	.32	.425	.5576
Speed of Ship	21.3	21.3	21.3
Revolutions	125	242	338
S. H. P.	23276	23847	27092
No. of Blades	3	3	3

The actual propellers of the *Pennsylvania* and of the *Utah* had the following dimensions:

	Pennsylvania	*Utah*
Diameter	12′-10″	9′-2″
Pitch	11′- 3½″	8′-6″
Proj. Area Ratio	.425	.5576

while the propellers of the *Delaware* were the same as for Propeller No. 1.

TRUE MEASURE OF ECONOMY; COMBINED ECONOMY OF ENGINES AND PROPELLERS.

The true measure of economy of propulsion for any vessel with any particular type of propelling machinery as compared

with the performance of a similar vessel equipped with a different type of engine, is not the measure and comparison of the steam economies of the types of engines but is the measure and comparison of the combined steam economies of the engines and the propulsive efficiencies of the propellers when driving the vessels at the same speeds under similar conditions of resistance.

To make such a comparison for the Standard vessel chosen, Fig. 2 has been prepared as a preliminary step towards the final comparison. The curves shown carrying the same letters of the alphabet as Fig. 1, are the values of "Pounds of Water per S. H. P. per hour ÷ Propulsive Coefficient at the same percentage of total designed power," where

$F_1 = F \div$ *Utah* P. C.
$F_{11} = F \div$ *Pennsylvania* P. C.
$C_1 = C \div$ *Utah* P. C.
$C_{11} = C \div$ *Pennsylvania* P. C.
$E = E \div$ *Pennsylvania* P. C.
$G = G \div$ *Pennsylvania* P. C.
$H = H \div$ *Pennsylvania* P. C.
$A = A \div$ *Delaware* P. C.
$B = B \div$ *Delaware* P. C.

and the letters preceding the equality sign refer to Fig. 2, and those following it to Fig. 1. By Fig. 2 is shown the relative costs per hour per S. H. P. at equal percentages of designed full power when using propellers No. 1, No. 2 and No. 3 which represent approximately the existing practices for propeller design for the various types of machinery under discussion. Such comparison does not satisfy when a direct comparison of the relative economies to be expected with any given vessel is sought in making the decision as to which type of propelling machinery will be the best to install, considered from the point of steam economy per knot traveled.

As the second step towards obtaining the desired comparison, Fig. 3 has been prepared. This Figure gives the

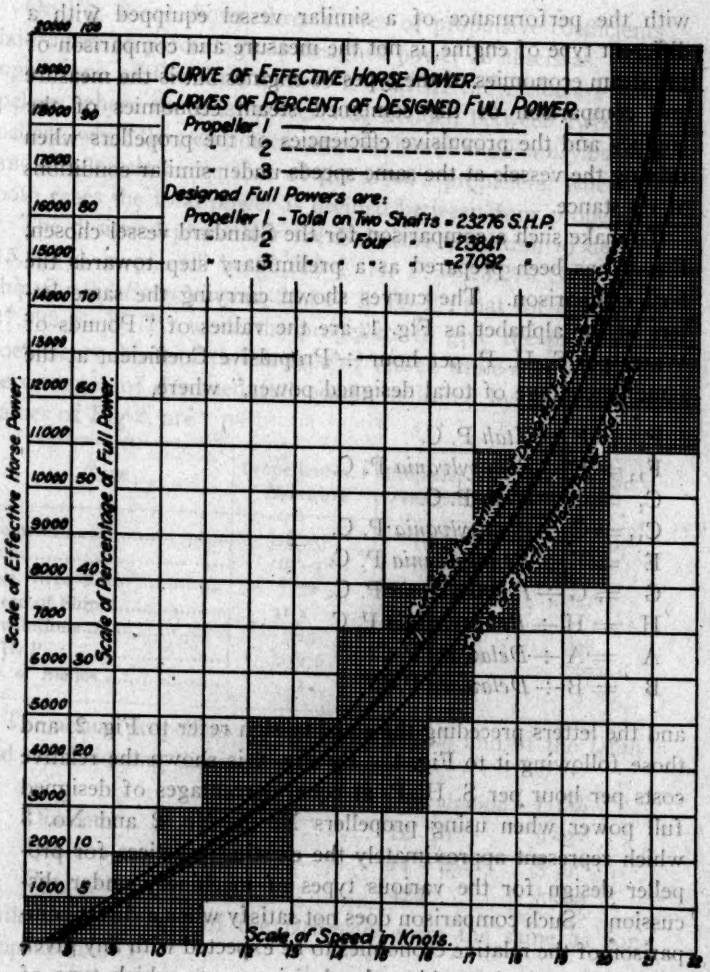

CURVE OF EFFECTIVE HORSE POWER.
CURVES OF PERCENT. OF DESIGNED FULL POWER.
Propeller 1
2
3
Designed Full Powers are:
Propeller 1 - Total on Two Shafts = 23276 S.H.P.
2 - Four - = 23847 "
3 " " " = 27092 "
Scale of Effective Horse Power.
Scale of Percentage of Full Power.
Scale of Speed in Knots.

Fig. 3.

" effective horsepower and Speed" curve for the Standard vessel and also gives the curves of " Percentage designed full power and speed" curves for propellers No. 1, No. 2 and No. 3.

By combining Figs. 2 and 3, Fig. 4 is obtained. This Figure shows directly the relative economies of engines and propellers for the Standard ship when running at the speeds given by the scale of abscissas. It must be borne in mind fully that the values given by the scale of ordinates are not pounds of steam per shaft horsepower but are such values divided by the propulsive coefficients which are usually obtained with the type of hull possessed by the Standard vessel and the different propellers which are fitted according to current practice.

Tabulating the results given by Fig. 4, for 21, 19, 15 and 10 knots, and giving 100 per cent as the efficiency of that combination which is the best at any given speed, also allowing an average correction of five per cent for electric propulsion in order to give an approximation to the actual economy of that system by allowing this percentage, which is small, for the cost of the main air, main circulating, forced lubrication and oil cooler pumps, we have:

No.	Letter	Type	Propeller No.	Measure of economy per cent. at Speed Knots			
				10	15	19	21
1	F-3	D. C. Curtis	3	43.1	59.6	66.2	70
2	C-3	D. C. Parsons	3	46.5	64.3	72.1	78.2
3	F-3-C	1 with Geared Cr.	3	56.1	67.5	66.2	70
4	D-3-C	2 with Geared Cr.	3	59.4	80	72.1	78.2
5	F-2	D. C. Curtis	2	55.5	71.4	78.2	80
6	C-2	D. C. Parsons	2	56.1	77.1	85	90.8
7	F-2-C	5 with Geared Cr.	2	76.2	77.8	78.2	80
8	D-2-C	6 with Geared Cr.	2	73.2	90	85	90.8
9	E-2	Parsons Geared	2	66.9	93.9	100	100
10	G-2	Curtis Geared	2	91.6	94.5	97.5	96.9
11	H-2	Electric Propulsion	2	100	100	96.9	97.8
12	A-1	Recip. Dry Steam	1	70.2	75	76.7	74.3
13	B-1	Recip. Sup. Steam	1	71 2	80	82.4	80

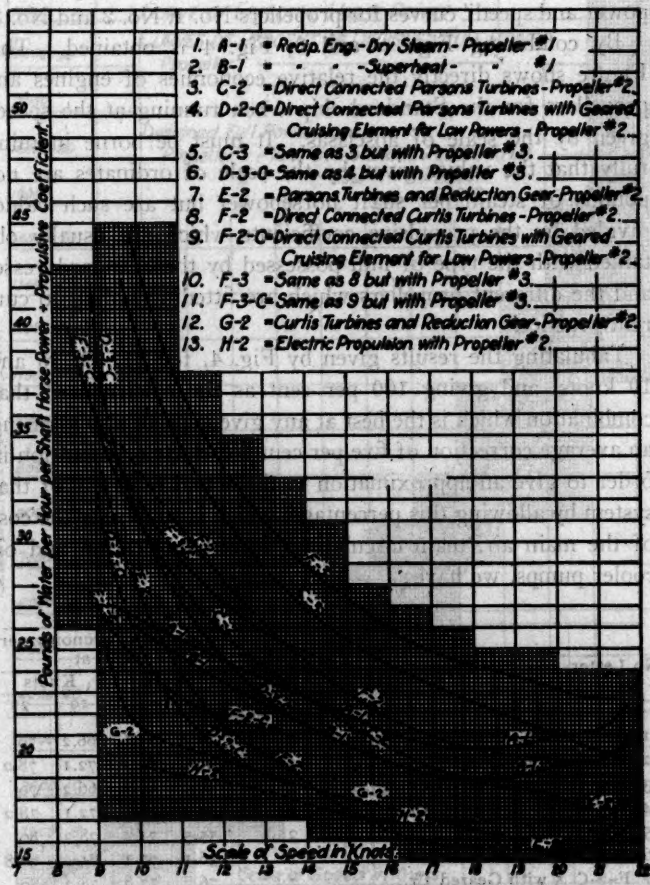

1. A-1 = Recip. Eng. - Dry Steam - Propeller #1
2. B-1 = " - " - Superheat - " - #1
3. C-2 = Direct Connected Parsons Turbines - Propeller #2.
4. D-2-C = Direct Connected Parsons Turbines with Geared Cruising Element for Low Powers - Propeller #2.
5. C-3 = Same as 3 but with Propeller #3.
6. D-3-C = Same as 4 but with Propeller #3.
7. E-2 = Parsons Turbines and Reduction Gear - Propeller #2.
8. F-2 = Direct Connected Curtis Turbines - Propeller #2.
9. F-2-C = Direct Connected Curtis Turbines with Geared Cruising Element for Low Powers - Propeller #2.
10. F-3 = Same as 8 but with Propeller #3.
11. F-3-C = Same as 9 but with Propeller #3.
12. G-2 = Curtis Turbines and Reduction Gear - Propeller #2.
13. H-2 = Electric Propulsion with Propeller #2.
Pounds of Water per Hour per Shaft Horse Power = Propulsive Coefficient.
50
45
40
35
30
25
20
15
A-1
B-1
C-2
G-2
Scale of Speed in Knots
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22

FIG. 4.

On examination of the foregoing Table and of Fig. 4, there is seen to exist a large difference between the economies of the Parsons direct connected turbine installations and those in which the Curtis marine turbine, direct connected, are used, with the difference decidedly in favor of the Parsons installations except where geared cruising elements are used. When such elements are fitted the Curtis installation with the medium speed propeller No. 2 is seen to be slightly superior from 10½ knots down. Both Parsons and Curtis installations with geared cruising units are superior in economy to the Parsons Geared installation at speeds below 14½ to 15 knots, but are both inferior to the Curtis geared at all speeds.

Furthermore, it is seen that the earlier superiority of the reciprocating engine practically disappeared when the propeller conditions for the other types of drives were changed from those represented by Propeller No. 3 to those of Propeller No. 2, and geared cruising elements were adopted.

With the adoption of the Direct Geared drive another advance in economy of propulsion was realized, that with Parsons turbines at the highest speed and at the high cruising speed of 19 knots standing number 1 on the list, being far superior to all the other types except electric propulsion and the Curtis Geared at these speeds, but being inferior at 10 knots to both number 7 and 8 conditions of the Table and being far inferior to condition numbers 10 and 11 of the same Table.

It is seen that condition number 11 is far superior in economy at all speeds up to and slightly above 15 knots, to all other types of machinery, yet at the higher speeds it is apparently very slightly inferior to both Geared drives. This inferiority is, however, so small that it is completely outweighed by the other advantages possessed by the Electric Drive and can be disregarded in making choice between the two types.

As to the Curtis marine turbine which shows up so well in the above comparison, its resort for assistance in raising its economy of propulsion to a still higher plane appears to be high superheat which it can use with a much greater degree of safety than can the Parsons turbine unless the latter be fitted with an impulse high pressure stage, a change which is bound to come in the next few years on this side of the water as it has already come on the other.

NAVY ESTIMATES OF THE PAST.

By George W. Baird, Rear Admiral (and formerly Chief Engineer), U. S. N., Retired, Member.

The great demonstration which took place on "preparedness day" in 1916, was a public declaration that "the American people" were urging appropriations for the National defense, and it re-kindled a desire, of the writer, to look up the estimates, and see if any of the neglect was due to "our people" of the Naval Service.

Old men live much in the past, and take satisfaction in defending their acts, even if they are "ancient history."

The search verified the fact that the estimates, for appropriation, as presented by the War Department and the Navy Department, including all the Bureaus, from the time of the Revolution, had clearly in view the strengthening of the Nation's defenses, and though these estimates were often "cut" in Committee and in the Body of Congress, there was evidence that it was done in the interest of economy, which is easily understood when it is remembered that so great a majority of "our people" live a long way from the sea board and a longer way from any belligerent power.

Before we had any outlying possessions to defend there was no apparent reason for increasing the Navy.

Urgent economy made it imperative to dismantle the Navy, discharge the personnel and lay up or sell the ships after the war for independence. This spirit of economy, though "penny-wise" prevailed until "preparedness day" in 1916.

In this search into "ancient history" the writer found some things of interest.

In the estimates for the year 1802, when the ships were appropriated for separately, there was more money asked for and appropriated for "spirits" than for beef and pork to-

gether, and we had pretty good men then. For one Frigate there was estimated 284 barrels of beef, at $13 = $2,692; 244 barrels of pork, at $18 = $4,392. And there was estimated 7,118 gallons of spirits, at $1.125 = $8,007.75.

We had four Frigates, of 44 guns each.
three of 36 guns each.
two of 32 guns each.
two of 32 smaller guns each.
one Schooner.

The larger Frigates had, each, one Captain; four Lieutenants; one Surgeon; one Purser; one Chaplain; one Sailing Master; two Surgeon's Mates; one Boatswain; one Sailmaker; one Carpenter; sixteen Midshipmen; two Master's Mates; two Boatswain's Mates; eleven Gunner's Mates; two Carpenter's Mates; one Captain's Clerk; one Coxswain, a Yeoman, a Cooper, a Steward, an Armorer, a Master-at-arms, a Cook.

The Captain was allowed eight rations, the Lieutenants three rations, etc., but the Petty-officers and crew only one ration. The grog ration was either whiskey, brandy, gin or rum, and was served twice a day, in "tots" of about one-and-a-half fluid ounces. The Ward-room officers' grog was usually placed in a pitcher, on the side-board, and was regarded as common Ward-room property. There were many officers who never touched it, but they never questioned the inherent right nor taste of their ship-mates.

The personnel, of that day, is of interest. All of the artificer class, as they are now called, were *bona fide* mechanics, having served indentured apprenticeships, as was the custom in that day. A "Jack-knife Carpenter" would not be tolerated. The Carpenters were *bona fide* ship-wrights; the Armorer a skilled smith, capable of making and tempering, dressing and grinding his own tools, and able to do any job in smithy required on board. The guns were all smooth-bore, muzzle-loaders, as simple as could be made, and the modern officer may ask why employ eleven gunner's mates?

There was a spirit of chivalry in the old Navy, inspired, no doubt, by that great man, John Paul Jones, who, in his advice to the Continental Marine Committee, specified:

"It is, by no means, enough that an officer of the Navy should be a capable mariner: He must be that, of course, but also a great deal more. He should be, as well, a gentleman of liberal education, refined in manner, punctillious courtesy, and the nicest sense of personal honor. He should not only be able to express himself clearly and with force in his own language, both with tongue and pen, but should be versed in French and Spanish.

"He should be the soul of tact, patience, justice, firmness and charity.

"No meritorious act of a subordinate should escape his attention or be left to pass without its reward, if even the reward be only one word of approval. Conversely he should not be blind to a single fault in any subordinate though, at the same time, he should be quick and unfailing to distinguish error from malice, thoughtlessness from incompetence, and well meant shortcoming from heedless or stupid blunder.

"As he should be universal and impartial in his rewards and approval of merit so should he be judicial and unbending in his punishment or reproof of misconduct."

SOCIETIES, ASSOCIATIONS AND COMMISSIONS PROMULGATING SPECIFICATIONS FOR ENGINEERING MATERIALS.

By K. D. Williams.

There are a number of societies, associations and commissions which have various functions utilized by Naval Engineers. In the course of planning and executing Naval Engineering work it is often necessary to consult and conform to standards, rules and regulations promulgated and enforced by many of the above. For the benefit of such Naval Engineers the following is written with the hope that it may prove of use as an index when special information or specifications are required.

The following list of societies, associations and commissions have been found during recent years to be the nearest associated with the Naval Engineer:

(*a*) Steamboat-Inspection Service, Department of Commerce, Washington, D. C.

(*b*) Bureau of Standards, Department of Commerce, Washington, D. C.

(*c*) American Bureau of Shipping, 66 Beaver Street, New York, John W. Coutillion, Secretary and Treasurer.

(*d*) American Society for Testing Materials, C. L. Warwick, Asst. Sec'y, University of Pennsylvania, Phila., Pa.

(*e*) American Society of Mechanical Engineers, W. E. Bullocks, Asst. Sec'y, 29 West Thirty-ninth St., New York, N. Y.

(*f*) Bureau of Explosives, Underwood Building, 30 Vesey St., New York, N. Y., J. E. Fairbanks, Sec'y and Treas.

(*g*) American Institute of Electrical Engineers, 33 Vesey St., New York, N. Y., F. L. Hutchinson, Secretary.

(*h*) Master Car Builders' Association, 746 Transportation Bldg., Chicago, Ill., V. R. Hawthorne, Acting Secretary.

(*i*) American Railway Engineering Association, Room 1011, 910 Michigan Avenue, Chicago, Ill., E. H. Fritch, Secy.

(*j*) American Institute of Weights and Measures, 20 Vesey St., New York, N. Y., Frederick A. Halsey, Commissioner and Secretary.

STEAMBOAT-INSPECTION SERVICE.

The Steamboat-Inspection Service is charged with the duty of inspecting vessels, the licensing of the officers and crew of vessels and the administration of the laws relative to such vessels and their officers for the protection of life and property.

The Supervising Inspector General and the Supervising Inspectors constitute a Board that meets annually at Washington, and establishes regulations for carrying out the provisions of the Steamboat-Inspection laws.

Publications.

1. *Laws Governing the Steamboat-Inspection Service.*

2. *General Rules and Regulations,* prescribed by the Board of Supervising Inspectors:

(*a*) Ocean and Coastwise.

(*b*) Great Lakes.

(*c*) Lakes other than the Great Lakes, Bays, and Sounds.

(*d*) Rivers.

3. *Pilot Rules:*

(*a*) Inland Waters of the Atlantic and Pacific Coasts and the Coast of the Gulf of Mexico.

(*b*) Western Rivers and the Red River of the North.

(*c*) Great Lakes.

Legal Status.

The act of Congress approved July 7, 1838, which provided for the inspection of the hulls and boilers of steam vessels, was the first legislation upon the important question of "the

better security of lives of passengers on board of vessels propelled in whole or in part by steam." By this act the inspectors were appointed by the district judge of the United States for the district in which the vessel was inspected, and were paid by the steamer the sum of $5.00 each for each inspection. This act provided for lifeboats, signal lights, fire pumps and hose, and also for iron rods or chains in place of rope for steering gear. The boilers were inspected every six months and the hulls every twelve months, and it was also required that steamers employ "a competent number of experienced and skillful engineers." Certificates of inspection were required "to be posted up and kept in some conspicuous part of the boat for the information of the public."

This act was modified by the act approved March 3, 1843, which provided for additional steering apparatus, but exempted certain vessels from the requirements of the previous act. The act of Congress approved March 3, 1849, provided for signal lights for all vessels.

The act of Congress approved August 30, 1852, was really the establishment of the present Steamboat-Inspection Service, and was known as the "steamboat act." This act amended the act of 1838, and provided for the appointment and payment of nine supervising inspectors, and for local inspectors at various ports. The act also provided for lifeboats, life-preservers, and other life-saving equipment, and for the licensing of engineers and pilots for passenger steamers, and for the stamping of boiler plate, and is really the foundation upon which the whole superstructure of the Steamboat-Inspection Service has been raised.

This act was modified and amended in minor particulars by the various acts of March 3, 1853, April 29, 1864, June 8, 1864, March 3, 1865, and July 25, 1866.

The act of Congress approved February 28, 1871, gave what is really the present law upon the organization and administration of the Steamboat-Inspection Service, and although amended and changed from time to time it is, in fact,

the basis of the present practice. This act provided for the appointment of a Supervising Inspector General and created the Board of Supervising Inspectors, designating also the time and place of meeting of said Board and defining the duties thereof. It provided for the inspection, testing, and stamping of material entering into the construction of marine boilers, a provision which has proven of the highest value and importance in the prevention of explosion and loss of life.

The bill upon which this legislation was based was prepared with much care, and its enactment was, without doubt, the wisest legislation ever devised upon these lines. It has served well the purposes for which is was designed and has fully justified the highest expectations entertained by those who supported it.

Legal Authority to Establish Standards or Conduct Inspections.

Under the provisions of Section 4405, R. S., the Supervising Inspectors and the Supervising Inspector General are required to assemble as a Board once a year in the City of Washington, District of Columbia, on the third Wednesday in January, and at such other times as the Secretary of Commerce shall prescribe, for joint consultation, etc., and that Board is required to establish all necessary regulations required to carry out in the most effective manner the provisions of Title 52.

Under the authority of Sections 4417 and 4418, R. S., the hulls and equipment and boilers of vessels with appurtenances are required to be inspected by the Boards of Local Inspectors.

Section 4438, R. S., gives Boards of Local Inspectors the authority to license and classify officers of vessels.

Section 4450, R. S., gives the Boards of Local Inspectors authority to investigate all acts of incompetency or misconduct committed by any licensed officer while acting under the authority of his license.

BUREAU OF STANDARDS.

The National Bureau of Standards was established by Congress to have the custody of standards, comparison of standards, preparation of standards, and the solution of problems which arise in connection with standards.

The standards with which the Bureau is authorized to deal may be conveniently classed as follows: Standards of measurements, standards of values of constants, standards of quality, standards of mechanical performance, and standards of practice.

Publications.

The Bureau of Standards publishes four series of publications:

(*a*) *Bulletins* which comprise the separate scientific papers covering researches of the Bureau within its field.

(*b*) *Technologic papers.*

(*c*) *Circulars* covering information of a technical or administrative character.

(*d*) *Miscellaneous publications.*

Legal Status.

The Organic Act of March 3, 1901, established the Bureau of Standards by stating that "the office of standard weights and measures shall hereafter be known as the National Bureau of Standards," and the same act expanded its functions to accord with the modern needs for standardization.

Successive acts such as the Legislative Appropriation Act, the Sundry Civil Act, and others have provided the necessary authority and funds for specific investigations.

Legal authority to establish standards and specifications as noted above was established by an act of Congress and supplemented by Section 3 of the Organic Act authorized the Bureau

to exercise its functions for the federal, state, or municipal, governments, societies, institutions, firms, corporations, or individuals.

AMERICAN BUREAU OF SHIPPING.

Quoting from the Constitution and By-Laws:

"The objects of the Bureau are as shown by the charter, and for the purpose of carrying out these objects the Bureau is to provide for shipowners, shipbuilders, underwriters, shippers, and all interested in maritime commerce, a faithful and accurate classification and registry of mercantile shipping, and to aid and develop the Merchant Marine of the United States of America."

The Bureau maintains a corps of inspectors whose duty is to inspect material both in the process of manufacture and fabrication and to inspect completed vessels and machinery; classification certificates are issued on the findings of these inspections.

Publications.

The Bureau publishes annually a "*Record of American and Foreign Shipping.*" This "Record" for the year 1918 has more than 1,100 pages, giving the following information:

List of Offices, where situated, etc.

List of Officers, Managers, Committees, Counsel, etc.

List of Surveyors and Ports. In this connection it may be said that there are Surveyors throughout the United States and in Foreign Ports all over the world.

List of Subscribers to the Record.

List of Vessels, including signal letters, name, rigging, nation, hailing port, registered dimensions, tonnage, when and by whom built, owners, engine and boilers, and memoranda as to classification, surveys, damage surveys, etc.

List of Owners and vessels owned by same.

List of Shipbuilders, Dry Docks and Marine Railways and Constructors of Marine Machinery and boilers throughout the world.

The Bureau also publishes semi-monthly or as often as needed, supplements to the "Record," giving particulars of new vessels and changes to old ones.

The Committees referred to above under "List of Officers" are: Executive, Finance and Audit, Naval Architecture, Engineering and Classification.

Legal Status.

The Bureau was incorporated under the laws of the State of New York, April 22, 1862, under the Title of "American Shipmasters' Association," and on September 26, 1898, the title was changed by legal authority to "American Bureau of Shipping."

The Bureau under its charter, Constitution and By-Laws examines the plans of vessels submitted for classification, approving same or making suggestions towards complying with the Rules governing the construction; and finally gives a certificate of class and of machinery, and when required assigns the least proper freeboard that the vessel may not be overloaded.

AMERICAN SOCIETY FOR TESTING MATERIALS.

The International Association for Testing Materials was formed at a conference of workers in experimental engineering held in Munich in 1882. Larger and more important meetings have subsequently been held and the membership now extends to thirty-one countries.

It was decided at the Stockholm Congress (1897) to encourage the consolidation of the membership in various countries into separate national organizations. In pursuance of this action the American members met in Philadelphia on

June 16, 1898, and organized under the name of the "American Section of the International Association for Testing Materials."

In 1902 the Association obtained a charter and was incorporated under the laws of the State of Pennsylvania under the name of the "American Society for Testing Materials." The American Society for Testing Materials is represented on the International Council by one member. The membership of the Society in 1918 was 2,261.

Purpose.

One of the most important functions of the Society as stated in its charter, is the standardization of specifications and the methods of testing. In pursuance of this activity the Society has adopted 128 standards covering ferrous and non-ferrous metals, cement, lime, gypsum and clay products, and certain miscellaneous materials such as preservative coatings, lubricants, road materials, rubber materials, rubber products, textile materials, etc. The Society has also published 49 tentative standards which is the term applied to a proposed standard which is printed in the Proceedings for one or more years with a view of eliciting criticism before final action is taken towards their adoption as standards.

Publications.

"*A. S. T. M. Standards*" are published triennially; the next publication will appear in 1921. From 1910 to 1916 the standards were published annually; from 1916 to June, 1918, when publication was put on the present basis, they were published biennially.

In addition to the publications of its standards the Society issued annually *Proceedings* of about 1,200 pages in two parts; Part I contains the committee reports and tentative standards, and Part II the technical papers presented at the annual meeting.

Each of the standards and tentative standards of the Society are available in separate pamphlet form. Any of the above publications may be purchased upon application to the Secretary.

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

The American Society of Mechanical Engineers was founded in 1880 "to promote the arts and sciences connected with Engineering and Mechanical Construction." The Society endeavors to accomplish this object through its meetings, general and section, held periodically through the United States; its publications—The Journal and Transactions—which are distributed free to its members, to libraries in exchange and to others by subscription; its large numbers of committees, working to develop the Society's usefulness in the mechanical engineering profession; and its library, located in New York City, but available to engineers throughout the country through the medium of the Library Service Bureau, a special library mail service.

Publications.

The Journal of the Society is published monthly. Features of the Journal are addresses, papers and discussions presented at general meetings of the Society, addresses, papers or discussions presented at Local Sections, and reviews of technical books by experts selected by the Publication Committee, etc.

The Transactions of the Society is published about July of each year and contains the more important addresses, papers and reports that have been presented at local section meetings during the preceding year.

The Year Book of the Society is published in February of each year and contains a list of its members, the Charter, Constitution, By-Laws and Rules of the Society, etc.

Legal Status.

The Society was organized as a corporation under the laws of the State of New York, April 7, 1880, its office being located in the City of New York.

C 56 of its constitution reads as follows: "The Society shall not approve any standard or formula, or approve any engineering or commercial enterprise. It shall not allow its imprint or name to be used in any commercial work or business."

It maintains a "Committee on Standardization" to formulate and revise standards of principal methods of procedure in Engineering practice. There are upward of fifty standards covering various engineering materials already created and these have been widely adopted and have become the basis of extensive manufactures.

BUREAU OF EXPLOSIVES.

In April, 1905, Mr. James McCrea, later President of the Pennsylvania Railroad, advocated before the American Railway Association the appointment of a committee to prepare regulations to govern the safe transportation of explosives.

This committee was appointed and with the aid of civilian experts in explosives, and consulting representatives of the Army and Bureau of Ordnance, Navy Department, prepared regulations, and the same were approved by the Association in October, 1905. No marked change resulted in the transporation of explosives until the Association in October, 1906, decided that some central agent of all roads was necessary for uniform enforcement of the regulations and a constitution and by-laws for the *Bureau for the Safe Transportation of Explosives and Other Dangerous Articles* were adopted.

In the following year the office of the Chief Inspector was opened in New York City. Seventy-eight companies at that time were members. The present membership comprises 244 railway companies.

At the present time the personnel of the Bureau consists of the Chief Inspector and office force, 23 Local Inspectors, 2 Special Agents, 3 Assistant Local Inspectors, a Chemist, an Assistant Chemist, and a Laboratory Assistant. The duties of the Inspectors are to investigate conditions at manufacturing plants, etc., and make reports to the designated operating officials in their districts and to the Chief Inspector.

The Federal law of May 30, 1908, now codified by the Act of March 4, 1909, as Sections 232 to 236, requires the Interstate Commerce Commission to formulate and the carriers to enforce reasonable regulations to promote safety.

The Bureau of Explosives submitted to the Interstate Commerce Commission a set of regulations for their consideration and with but a few changes were adopted and were prescribed to take effect October 1, 1908.

The Bureau has prepared specifications for containers for the transportation of gases both liquefied and non-liquefied, and files the history and records of their manufacture and test as well as data on containers for the transportation of other dangerous articles.

The cost of maintaining the Bureau is shared by its members, an assessment being levied each six months by the Executive Committee.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

Quoting an extract from its constitution the purpose of the Institute is stated as follows:

"Its objects shall be the advancement of the theory and practice of Electrical Engineering and of the allied Arts and Sciences and the maintenance of a high professional standing among its members. Among the means to this end shall be the holding of meetings for the reading and discussion of professional papers and the publication of such papers, discussions and communications as may seem expedient."

Publications.

The *Proceedings* are issued at the beginning of each calendar month and have two principal divisions: The first part contains matter of transient interest, such as announcements, election of members, personal notes, reports of the meetings of Sections and Branches, and general information pertaining to the Institute. Technical papers and other matters of an engineering character are contained in the second part.

The *Transactions* are published in one or more bound volumes each year, and consist of technical papers and discussions, reports, and other matter, previously published in the monthly Proceedings, deemed worthy of permanent record.

Legal Status.

The Institute was incorporated on March 16, 1896, under the Membership Corporations Law, Section 5, of the laws of the State of New York.

The Institute does not conduct inspections of any kind. It has established electrical standards, relating to the rating and testing of electrical equipment, but not including specifications of design and dimensions. These standards have been revised from year to year as a result of changes and developments in the electrical art. The Institute is also affiliated with the International Electrotechnical Commission and its standards conform to those adopted by the Commission. These standards, known as the Standardization Rules of the A. I. E. E., are universally accepted as official by engineers throughout the country. The Rules were not formulated under any legal authority, but as one of the proper functions of the national organization representing the electrical profession.

MASTER CAR BUILDERS' ASSOCIATION.

The Master Car Builders' Association was originally composed of master car builders and foremen of railway car shops, and was organized at Altoona, Pennsylvania, September, 1867.

In June, 1881, an amendment to the constitution was proposed, and in October, 1882, this amendment creating a new class of members called "representative members" was adopted. This amendment permitted each railroad to be represented in direct proportion to the number of cars it owned. The number of cars represented in the Association is approximately 2,800,000. Its membership extends to England, France, Russia, India, Australia, Japan, China, Argentina, Chile, Brazil, Cuba and the Philippines.

Purpose.

Quoting from information furnished to the Railroad Administration by the Association's late secretary, Mr. Joseph W. Taylor, the purpose of the Association is as follows:

"The objects of the Association are the advancement of knowledge concerning the construction, maintenance and service of railroad cars and the parts thereof, by investigations through committees and discussions in conventions; to provide an organization through which the members and the companies they represent may agree upon such joint action as may be required to bring about uniformity and interchangeability in the parts of railroad cars; to improve their construction and to adjust the mutual interest growing out of their interchange and repair, but the action of the Association shall have a recommendatory character, and shall not be binding upon any of its members or the companies represented in it."

This Association was responsible for the adoption of automatic couplers for cars in 1887 and the automatic air brake in 1888. Through their efforts also standards for 62 different parts of cars have been adopted.

The standardization of parts of cars and method of loading same is of the greatest value when it is considered how often cars are shifted from one road to another and many repairs are necessarily performed while a great distance from their home shops.

AMERICAN RAILWAY ENGINEERING ASSOCIATION.

Purpose.

The object of the American Railway Engineering Association is the advancement of knowledge pertaining to the scientific and economic location, construction, operation and maintenance of railways.

Publications.

The American Railway Engineering Association publishes: "*The Monthly Bulletin*," issued ten times per year (May and June omitted);

"*The Annual Proceedings*," issued annually;

"*The Manual for Railway Engineering and Maintenance of Way Work*," issued at intervals of from three to five years. Supplements thereto are issued annually.

Legal Status.

The American Railway Engineering Association is incorporated under the laws of the State of Illinois "not for profit."

Legal authority to establish standards or conduct inspections: The recommendations of the Association are not binding upon the members of companies with which it is connected, but the standards are recommendatory.

The Association does not make "inspections" but has made and is continually making experimental tests of various kinds, the results of which are published for the information and benefit of the members of the organization and railroad companies generally. Such tests cover:

The effect of moving loads on railroad bridges,
Tests on columns (bridge),
Tests of rail joints,
Tests of water columns,
Strength of bridge timbers, etc.

AMERICAN INSTITUTE OF WEIGHTS AND MEASURES.

Quoting from the constitution of the above Institute adopted June 28, 1916, and amended February 17 and 19, 1917, its object is:

"(*a*) The maintenance and improvement of our present (English) system of weights and measures, for the good of our commerce and industry and the well-being of our country.

"(*b*) The education of the people with respect to the importance of our weights and measures, through the dissemination of correct information with respect to them and to the danger inherent in changes of our basic standards of measurement.

"(*c*) The improvement of old and the development of additional standards as they may be needed by reason of new conditions in commerce, industry, science, and engineering.

"(*d*) The promotion of wise legislation for the conservation of our basic English units of weight and measure, and opposition to hasty and ill-considered legislation involving changes from our fundamental English standards."

The Institute publishes a quarterly report of activities issued to members alone. Two Reports on The Metric System in Export Trade and on the Weights and Measures of Latin America have been issued, as well as five bulletins on the following subjects:

Bulletin No. 1—"The Six Metric Myths."

Bulletin No. 2—"Endorsements That Count."

Bulletin No. 3—"The American Metric Association and the Metric System in Munitions of War."

Bulletin No. 4—"The Bushel Standard."

Bulletin No. 5—"Extracts from Reports of British Parliamentary Committees Relating to the Metric System."

The Legal Status of the Institute is that of an unincorporated Society.

RELATIONS OF SOCIETIES TO NAVAL ENGINEERING.

(*a*) *Steamboat-Inspection Service Rules.* Material for use in the Naval Service is seldom purchased in strict accordance with these rules. They have occasionally been used in the past in specifying material for Naval Auxiliary Ships.

(*b*) *Bureau of Standards.* The Navy Department has consulted the Bureau of Standards on new developments where special experimental work has been necessary. During the late war, assistance has been rendered by the Bureau of Standards in investigations and experiments of engineering materials, such as brasses, bronzes and bearing metals, with the view of conserving tin; also in Aircraft materials and gasses.

(*c*) *American Bureau of Shipping.* For vessels of types similar to those mentioned under "American Society of Mechanical Engineers," and for the same reasons, the machinery is often purchased in accordance with the Rules of the American Bureau of Shipping, and other materials are occasionally specified to the above rules.

(*d*) *American Society for Testing Materials.* The specifications of this Society are employed more as references. Navy material such as structural steel for ships and rivets have been purchased in strict accordance with the specifications of this society.

(*e*) *American Society of Mechanical Engineers.* The boilers for such Naval vessels as colliers, oil tankers, repair ships, sea going and Harbor tugs, etc., are ordered often to be in accordance with the A. S. M. E. Boiler Code. This practice is sometimes followed to expedite deliveries and obtain material at a lower cost than if purchased in full accordance with the Navy Department Specifications. As a rule material purchased in accordance with the A. S. M. E. Boiler Code is inspected at the place of manufacture by representatives of the Navy Department.

(*f*) *Bureau of Explosives.* All cylinders or containers for the transportation of gases such as Hydrogen, Oxygen, Helium, Acetylene, Carbonic Acid Gas, Anhydrous Ammonia, etc., are purchased in accordance with the rules or specifications of this Bureau in order that they may comply with the Interstate Commerce rules and be accepted for transportation by the several transportation companies. These rules or specifications are incorporated in the Navy Department leaflet specifications for the containers for the several gases. Containers for the shipment of ammunition and other dangerous articles are also purchased in accordance with the rules and specifications of the Bureau of Explosives.

(*g*) *American Institute of Electrical Engineers.* Motors and controllers which bidders guarantee to give satisfactory operation after installation and certify that they are in full conformity with the A. I. E. E. standardization rules are often accepted for Navy Yard use in lieu of motors and controllers in full accordance with the Navy Department Specifications.

Attention is invited to a clause permitting the above in "General Specifications and Instructions Governing Submission of Proposals for Furnishing Machine Tools for the United States Navy," dated March 15, 1916.

The rules in question are not generally regarded as specifications but are considered an authority in regard to methods of conducting tests, calculating efficiency and other characteristics of motors, generators and transformers; and definitions of various terms used in connection with specifications and tests.

(*h*) *Master Car Builders' Association.* It is necessary for the rolling stock in the various Navy Yards and stations to be in accordance with the rules and specifications of the M. C. B. to insure facilities for the handling of cars belonging to the various railroads and in some cases transporting Navy owned cars over private owned roads.

(*i, j*) *The publications of the American Railway Engineering Association and the American Institute of Weights and Measures* are employed as references by Naval Engineers in charge of creating and modifying Navy Department Specifications.

PROPELLER DATA FROM U. S. S. *NEW MEXICO'S* TRIALS.

By Commander S. M. Robinson, U. S. Navy, Member.

In the February, 1915, issue of this Journal there was published certain data on the subject of propellers in connection with the design of electric machinery for ship propulsion. It has been possible to check some of this data by the recent trials of the *New Mexico* and this article will compare the data of that issue of the Journal with the data obtained from the actual trials of the *New Mexico*. In addition, there will be given certain original information that was obtained in regard to propellers and propulsion generally.

The *New Mexico* held two sets of trials. The first trial was held after the ship had been out of dock about seven weeks. The second trial was held just after the ship had been docked. These two trials have been analyzed and the analysis is given in Table 1. From this it will be seen that there was a difference between the two trials of about 4,250 shaft horsepower at 21 knots, due to the foul condition of the ship's bottom; this increase in resistance, expressed as a percentage, amounted to about 9.6 per cent on the average. This experience of the *New Mexico* was corroborated by that of the *Pennsylvania;* this ship had been out of dry dock for a few weeks and it was decided to try the ship without cleaning her bottom, but a preliminary run demonstrated that the increase of horsepower was so great that it would be impossible to fulfill the guarantee of fuel consumption without docking the ship. It would seem that fouling occurs very rapidly in the first few weeks that a ship is out of dry dock and after that the rate of increase of resistance due to fouling falls off very rapidly.

U.S.S. NEW MEXICO.

HULL DATA
Length = 600'
Beam = 97'
Draft = 30'
Displacement = 32000 Tons.
$\frac{A}{LWL}$ = .1617
NBC = .641
SBC = .63
K = 1

PROPELLER DATA
$\frac{A_E}{A_O}$ = .3567
P = 15.167
D = 13.412
EHP = 21500
SHP = 30520
V = 24.85
S = .099

12f TRIAL

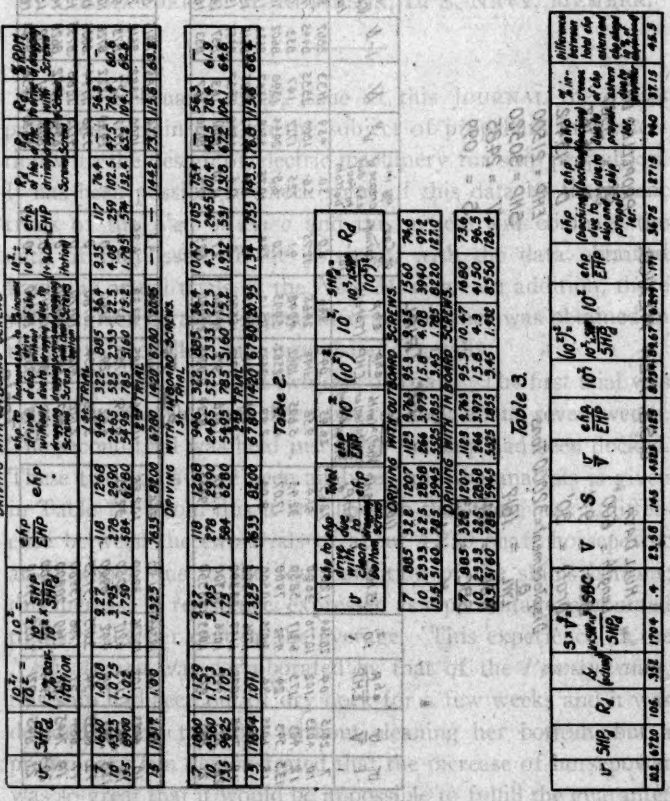
σ	$\frac{V}{\sqrt{L}}$	$\frac{ehp}{EHP}$	$\frac{n}{10}$	S.HP$_d$	$\frac{(10^3)^{4/3} \times S.HP}{S.HP_d}$	$\frac{10^{12} \times (\text{units completion number})^{4/3}}{S.HP_d \text{ (millions)}}$	$\frac{ehp}{EHP}$	ehp (Total)	% Correlation $(\frac{ehp}{10^3})^2 - 1$	% increase of ehp due to foul bottom	V^y	N^y	$1-N$	R_d (Calculated)	R_d (actual)
7	.2815	.64	28.544	1200	7283	26.95	.644	946	6.0	5.0	459	.1133	.8867	52.7	56.5
10	.4025	.102	10.776	3600	91.4	9.56	.1196	2465	12.75	5.6	1000	.1555	.8445	79.1	81.0
12	.483	.173	6.217	5850	32.43	5.695	.1882	4048	9.1	7.25	1717	.147	.853	94.0	96.1
13.5	.543	.24	4.98	7900	17.07	4.131	.2562	5495	7.0	6.5	2444	.1398	.8602	104.8	107.5
15	.6035	.34	3.875	10500	8.94	2.99	.3483	7510	2.86	10.75	3318	.1367	.8633	116.2	118.3
17	.684	.57	1.796	15300		1.995	.515	11075	0	8.9	4773	.1385	.8615	131.8	135.5
19	.7645	.875	1.149	23300		1.31	.7717	16590	0	11.4	6548	.1537	.8463	150.0	152.0
20.5	.825	.949	1.056	30500	1.057	1.028	.976	20980	2.7	12.10	8081	.163	.837	163.7	164.4
21	.845	.971	1.033	33350	.9435	.9729	1.0266	22080	6.25	7.5	8630	.167	.833	168.5	169.0

20d TRIAL

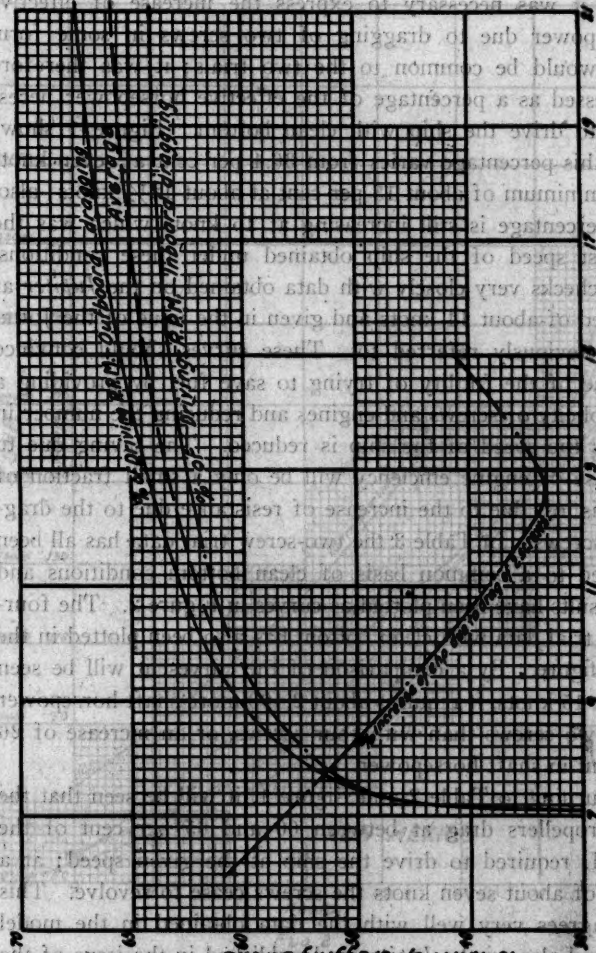
σ	$\frac{V}{\sqrt{L}}$	$\frac{ehp}{EHP}$	$\frac{n}{10}$	S.HP$_d$	$\frac{(10^3)^{4/3} \times S.HP}{S.HP_d}$	$\frac{10^{12} \times (\text{units completion number})^{4/3}}{S.HP_d \text{ (millions)}}$	$\frac{ehp}{EHP}$	ehp (Total)	% Correlation $(\frac{ehp}{10^3})^2 - 1$	% increase of ehp due to foul bottom	V^y	N^y	$1-N$	R_d (Calculated)	R_d (actual)
7	.2815	.64	28.544	1150	7540	27.5	.644	885	3.5		459	.1085	.8915	52.5	56.3
10	.4025	.102	10.776	3200	102.26	10.136	.1085	2339	6.35		1000	.1382	.8618	77.5	78.4
12	.483	.173	6.217	5050	37.55	6.129	.1753	3775	1.4		1717	.127	.873	91.9	93.0
13.5	.543	.24	4.42	6900		4.42	.24	5160	0		2444	.1222	.8778	102.8	104.1
15	.6035	.34	3.073	9175		3.926	.3541	6780	0		3318	.1194	.8806	113.8	115.6
17	.684	.57	1.796	13980		2.132	.4728	10170	0		4773	.1265	.8735	130.0	132.9
19	.7645	.87	1.149	20800		1.467	.6973	14890	0		6548	.1372	.8628	147.2	149.2
20.5	.825	.949	1.068	26900		1.156	.87	18710	0		8081	.141	.859	159.5	161.7
21	.845	.971	1.033	29100		1.049	.9538	20550	0		8630	.1456	.8544	164.2	166.7

Table 1.

The ship was also standardized, using only two screws to drive the ship; four points were obtained altogether; three points on the first trials, and one point on the second trials; in each case the points were determined for the inboard and for the outboard screws separately. These trials were run with



the motor disconnecting switches open on the idle motors so that the dragging screws were perfectly free to turn. The results of this standardization have been analyzed in Table 2 and plotted as curves in Figure 1. As part of the data was


Knots.
Fig. 1.

obtained on the trials with bottom clean and part with bottom foul, it was necessary to express the increase of effective horsepower due to dragging of two screws in some form that would be common to the two trials; it was therefore expressed as a percentage of the effective horsepower necessary to drive the ship with clean bottom. Figure 1 shows that this percentage varies from 36.4 per cent at seven knots to a minimum of about 13 per cent at about 12½ knots; also, the percentage is still increasing at 15 knots which was the highest speed of the ship obtained under these conditions. This checks very closely with data obtained on the *Jupiter* at a speed of about 14 knots and given in the issue of the JOURNAL previously referred to. These curves should convince anyone of the futility of trying to save fuel by providing a multiplicity of screws and engines and reducing the number in use as the speed of the ship is reduced. The saving due to increase of engine efficiency will be only a small fraction of what is lost due to the increase of resistance due to the dragging screws. In Table 3 the two-screw trial data has all been reduced to a common basis of clean bottom conditions and the results have been plotted as curves in Figure 2. The four-screw trial data with clean bottom has also been plotted in the same figure. By a comparison of the curves, it will be seen that at 15 knots, it requires about 2,400 more shaft horsepower with two screws than with four screws, or an increase of 26 per cent in shaft horsepower.

Returning to Table 2 and Figure 1, it will be seen that the idle propellers drag at between 60 and 65 per cent of the R.P.M. required to drive the ship at the given speed; at a speed of about seven knots the screws cease to revolve. This data agrees very well with the data obtained in the model tank and also on the *Jupiter* and published in the issue of the JOURNAL previously referred to. On the *Jupiter*, the dragging screws ran at about 68 per cent of the normal R.P.M. required to drive the ship. As this percentage seems to be about the

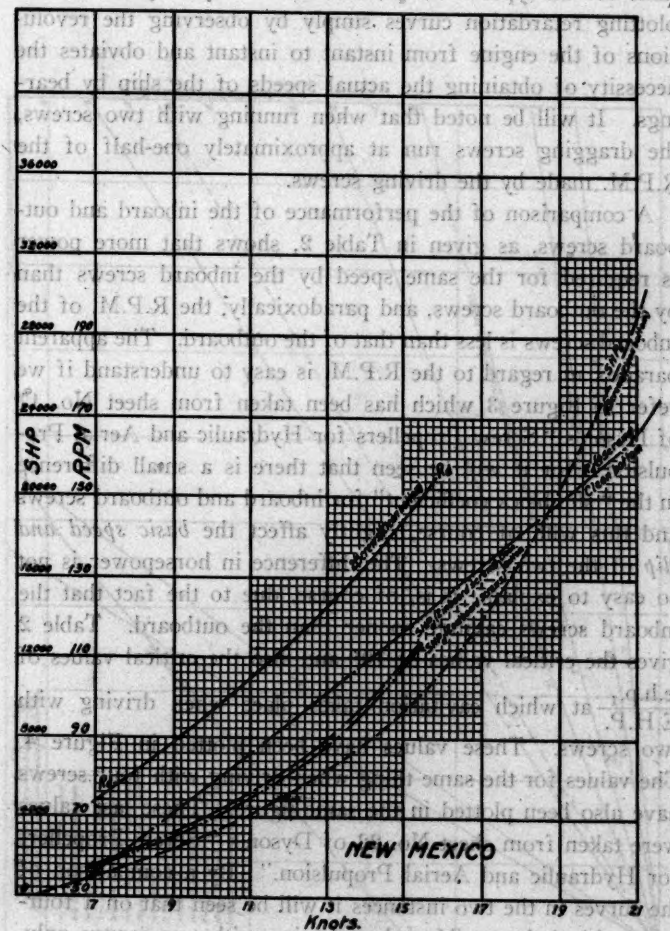


Fig. 2.

same for all types of ships, it offers a very easy method of plotting retardation curves simply by observing the revolutions of the engine from instant to instant and obviates the necessity of obtaining the actual speeds of the ship by bearings. It will be noted that when running with two screws, the dragging screws run at approximately one-half of the R.P.M. made by the driving screws.

A comparison of the performance of the inboard and outboard screws, as given in Table 2, shows that more power is required for the same speed by the inboard screws than by the outboard screws, and paradoxically, the R.P.M. of the inboard screws is less than that of the outboard. The apparent paradox in regard to the R.P.M. is easy to understand if we refer to Figure 3 which has been taken from sheet No. 17 of Dyson's "Screw Propellers for Hydraulic and Aerial Propulsion," for it will be seen that there is a small difference in the "slip block coefficient" for inboard and outboard screws and this will, of course, slightly affect the *basic speed and slip* of the two screws. The difference in horsepower is not so easy to explain; it is, of course, due to the fact that the inboard screws cavitate sooner than the outboard. Table 2 gives the critical values of 10^n and also the critical values of $\frac{\text{e.h.p.}_1}{\text{E.H.P.}}$ at which cavitation takes place when driving with two screws. These values have been plotted in Figure 4. The values for the same thing when driving with four screws have also been plotted in the same figure. These last values were taken from sheet No. 22 of Dyson's "Screw Propellers for Hydraulic and Aerial Propulsion." By a comparison of the curves in the two instances it will be seen that on a four-screw ship it is possible, when driving with two screws only, to load these screws very much more heavily before cavitation takes place than can be done when driving with four screws, although the slip of the screw is more than twice as great with the two-screw condition as with the four-screw condition.

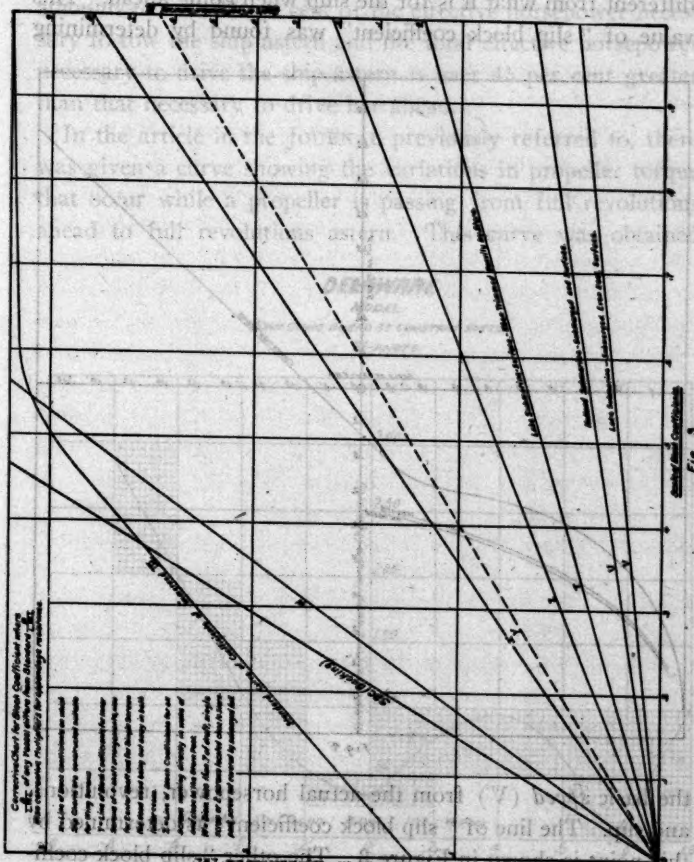


Fig. 3

The ship was also standardized at one speed, when going astern. This data has been analyzed in Table 4. It will be seen that the "slip block coefficient" in this case is quite different from what it is for the ship when going ahead. This value of "slip block coefficient" was found by determining

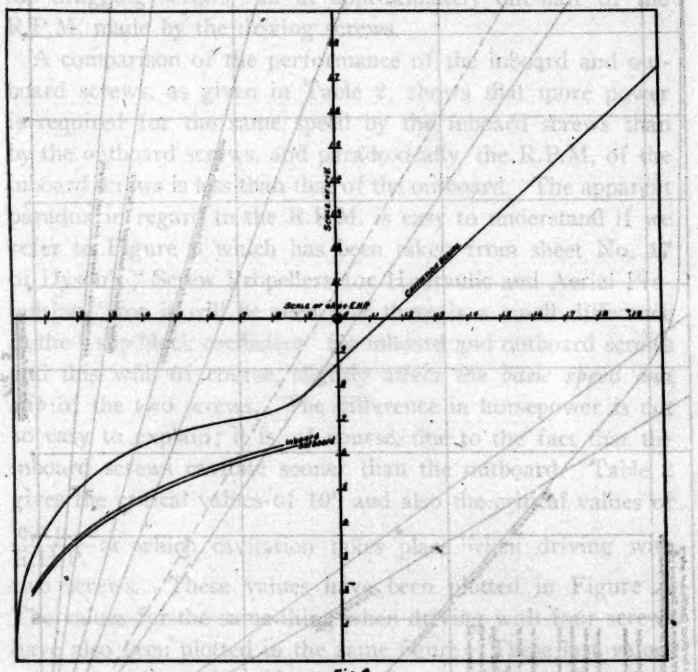


Fig. 2

the basic *speed* (V) from the actual horsepower, revolutions, and slip. The line of "slip block coefficient" as determined by this point is shown in Figure 3. The other "slip block coefficient" lines shown in the same figure have been taken from sheet No. 17 of Admiral Dyson's book. From a comparison of the two, it will be seen that the "slip block" for a ship going astern is radically different from what it is for a ship

going ahead. Table 4 shows very clearly the enormous increase in effective horsepower, due to the reaction of the water thrown against the stern of the ship. In this case it amounts to over 37 per cent of the effective horsepower necessary to tow the ship astern and the total effective horsepower necessary to drive the ship astern is over 45 per cent greater than that necessary to drive her ahead.

In the article in the JOURNAL previously referred to, there was given a curve showing the variations in propeller torque that occur while a propeller is passing from full revolutions ahead to full revolutions astern. This curve was obtained

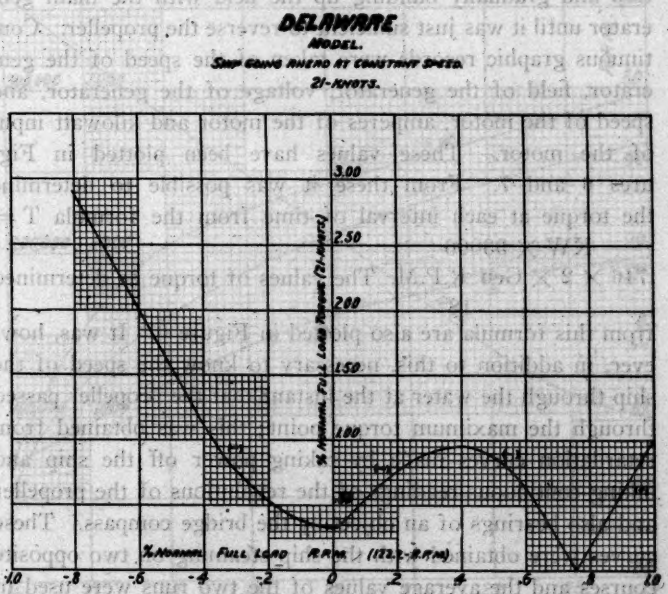


FIG. 5.

from model tank experiments and is reproduced in this article as Figure 5. The most vital part of this curve, so far as it affects induction motor design, is the maximum torque point

of the propeller during the period in which it is being brought to rest. In Figure 5 the value of the torque at this maximum point is about 95 per cent of the torque required to drive the ship at full speed. Data obtained from the *Jupiter* indicated a considerably lower value for this point—about 75 per cent. It was, therefore, very desirable to get a check on the point by the *New Mexico;* the value of the point on the *New Mexico* was found to be about 106 per cent at 18 knots; at the same speed, the model tank curves agree fairly closely, showing about 112 per cent. The value of the torque at this point was obtained by setting the motor switches in the reversing position and gradually building up the field with the main generator until it was just sufficient to reverse the propeller. Continuous graphic records were taken of the speed of the generator, field of the generator, voltage of the generator, and speed of the motor, ampères of the motor and kilowatt input of the motor. These values have been plotted in Figures 6 and 7. From these it was possible to determine the torque at each interval of time from the formula $T = \frac{KW \times 33000}{.746 \times 2 \times \frac{\text{Gen. R.P.M.}}{18}}$ The values of torque as determined from this formula are also plotted in Figure 6. It was, however, in addition to this, necessary to know the speed of the ship through the water at the instant that the propeller passed through the maximum torque point; this was obtained from retardation curves made by taking power off the ship and taking continuous readings of the revolutions of the propeller and also bearings of an object by the bridge compass. These curves were obtained with the ship steaming on two opposite courses and the average values of the two runs were used in plotting. This data is shown in Figure 8. To determine the point at which the propeller actually passed through its maximum torque it was assumed that this was when the propeller R.P.M. was 35 per cent of the R.P.M. corresponding to the

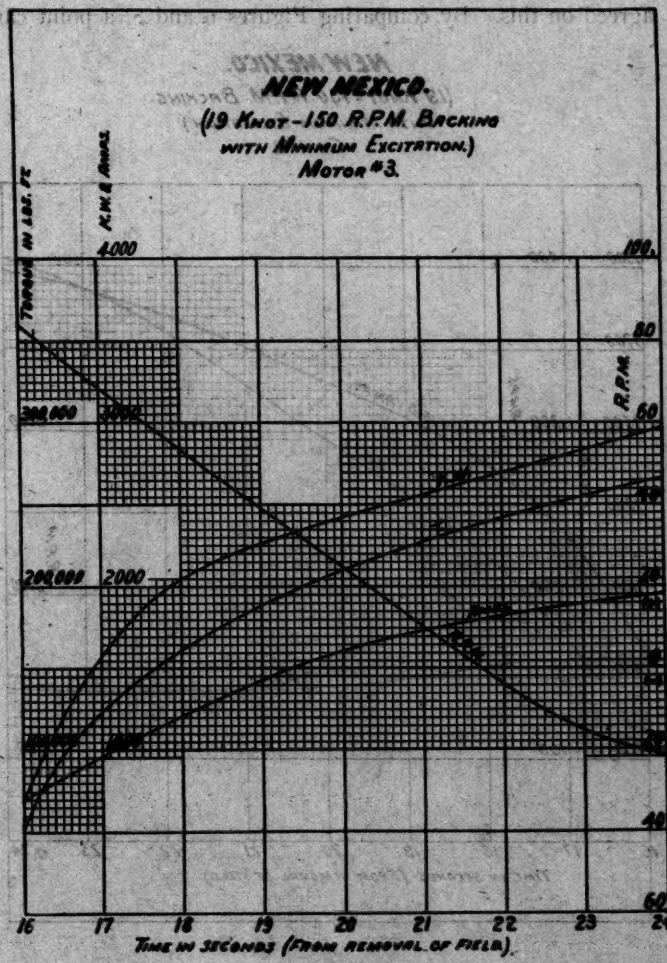

NEW MEXICO.
(19 Knot - 150 R.P.M. Backing
with Minimum Excitation.)
Motor #3.
Torque in Lbs. Ft.
K.W. & Amps.
R.P.M.
4000
300,000
200,000
2000
190
80
60
40
16
17
18
19
20
21
22
23
24
Time in Seconds (From Removal of Field).

Fig. 6.

speed of the ship, as both *Jupiter* and model tank curves agreed on this. By comparing Figures 6 and 8, a point can

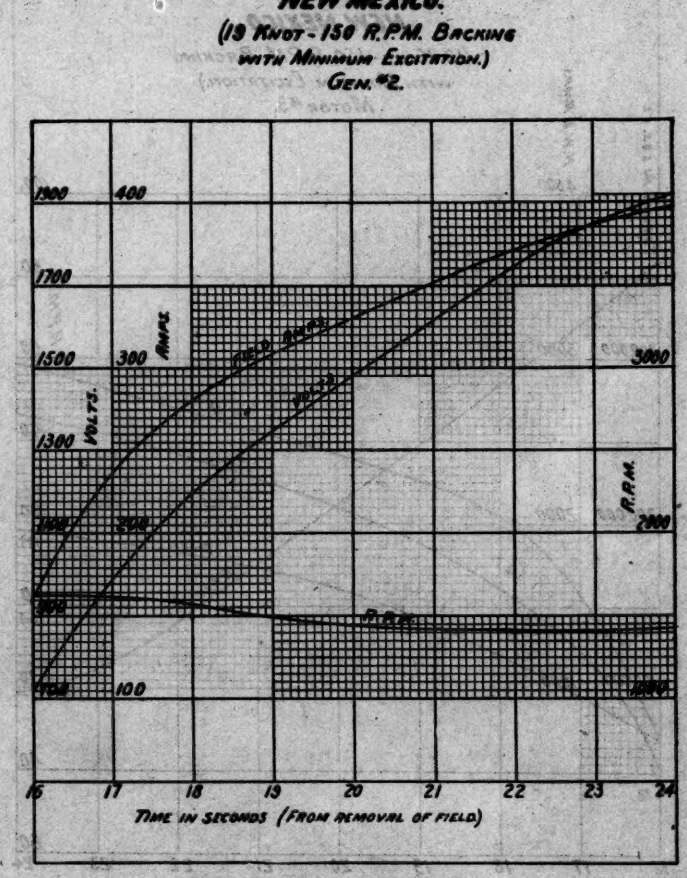


Fig. 7.

be found where the motor R.P.M. are just 35 per cent of the R.P.M. required to drive the ship; the torque at this point,

as given by the curve in Figure 6, will be the maximum torque required to bring the propeller to rest.

The curves in Figure 8 show that it requires about 15 seconds for the propeller to drop down to the actual dragging revolutions corresponding to the speed of the ship. This is also an important point in connection with induction motor design, as it affects the available torque of the motor for reversing. These curves are very similar to curves of the *Jupiter* given in the issue of the JOURNAL, previously referred to; in the same issue, there was outlined a method for calculating the deceleration of a ship and a curve was worked out for the *New Mexico*, using this method; this curve is reproduced in Figure 8 as the dotted curve, and it will be seen that it is in very close agreement with the actual curve.

There is one other point in connection with electric propulsion that was discussed in the previous issue of the JOURNAL, and that is the "turning of ships." Experiments were made on the *Jupiter* and the *Delaware* by turning these ships and keeping the revolutions per minute of the engines constant. This is the condition that obtains with an engine controlled by a governor. The experiments made on the *Jupiter* and *Delaware* were repeated on the *New Mexico*. The trials carried out on the first two ships were at low speeds, being 12 and 14 knots on the *Jupiter* and 12 knots on the *Delaware*. Turns were made on the *New Mexico* at 14.5 knots, using one generator, and at 19.5 knots, using both generators. On the *Delaware*, the total increase of power due to turning was 39 per cent when using 25 degree of rudder, on the *Jupiter* it was 29 per cent. On the *New Mexico*, at 14.5 knots, the increase was 50 per cent, and at 19.5 knots the increase was 30 per cent, but this does not represent the final limit of increase at 19.5 knots, as the limit of power was reached on the turbine before maximum power was reached. These percentages are affected by the speed of the ship, by the size of the rudder, and by the rudder angle used, so that it is difficult

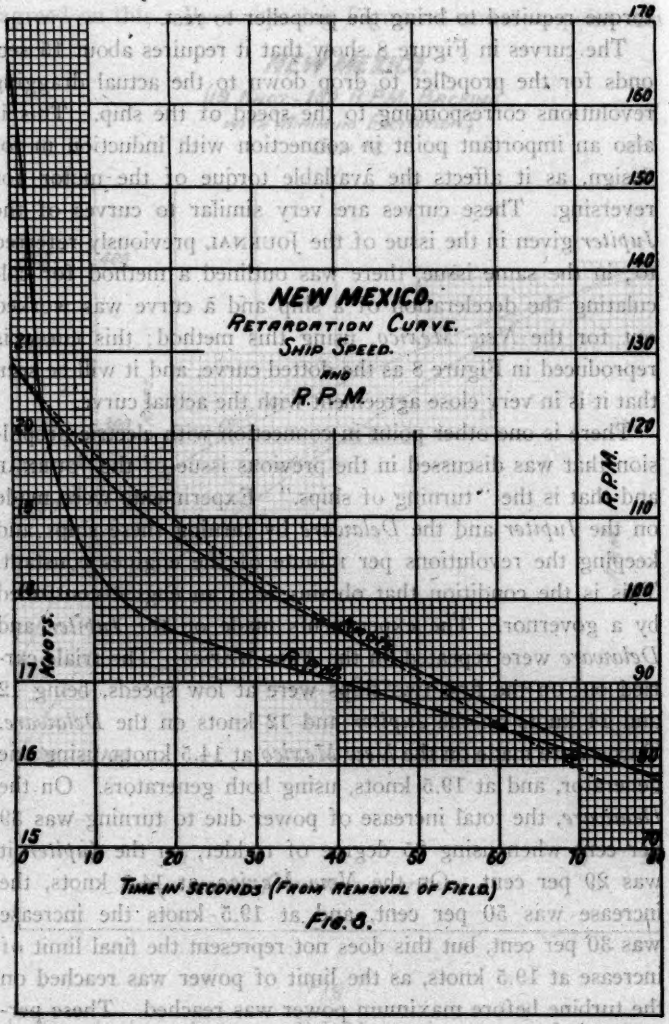
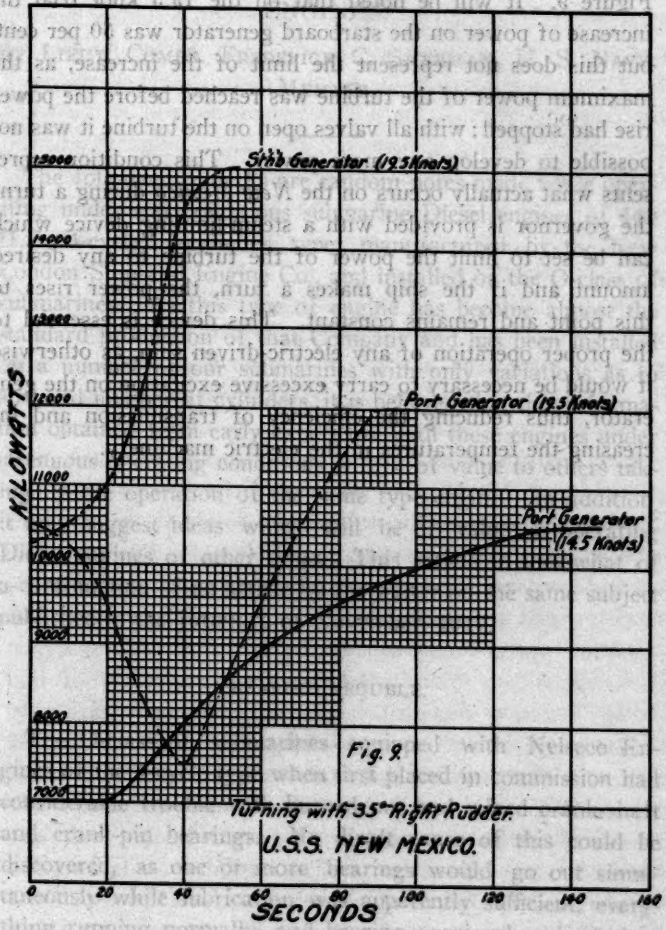
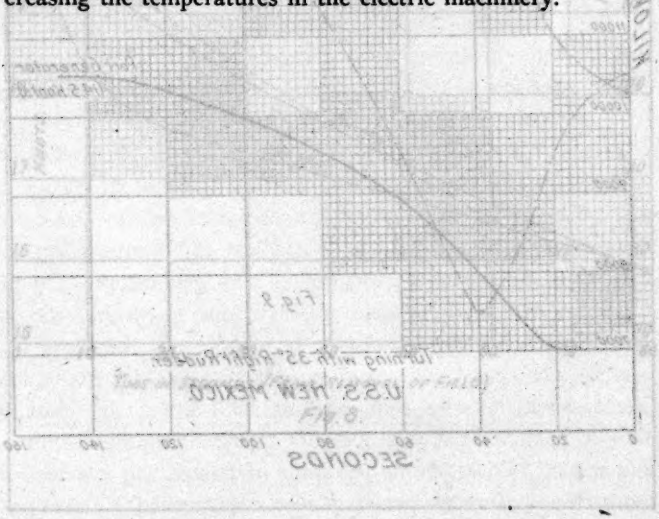

NEW MEXICO.
RETARDATION CURVE.
SHIP SPEED.
AND
R.P.M.
KNOTS.
R.P.M.
SPEED
R.P.M.
170
160
150
140
130
120
110
100
90
80
70
60
21
20
19
18
17
16
15
0
10
20
30
40
50
60
70
80
TIME IN SECONDS (FROM REMOVAL OF FIELD)

FIG. 8.


Stbd Generator (19.5 Knots)
Port Generator (19.5 knots)
Port Generator (14.5 Knots)
KILOWATTS
15000
14000
13000
12000
11000
10000
9000
8000
7000
0
20
40
60
80
100
120
140
160
SECONDS
Fig. 9.
Turning with 35° Right Rudder.
U.S.S. NEW MEXICO.

to predict what this percentage will be in any given case. The curves obtained from the *New Mexico's* trials are given in Figure 9. It will be noted that on the 19.5 knot trial the increase of power on the starboard generator was 50 per cent, but this does not represent the limit of the increase, as the maximum power of the turbine was reached before the power rise had stopped; with all valves open on the turbine it was not possible to develop any more power. This condition represents what actually occurs on the *New Mexico* during a turn; the governor is provided with a steam-limiting device which can be set to limit the power of the turbine to any desired amount and if the ship makes a turn, the power rises to this point and remains constant. This device is essential to the proper operation of any electric-driven ship, as otherwise it would be necessary to carry excessive excitation on the generator, thus reducing the efficiency of transmission and increasing the temperatures in the electric machinery.



NOTES ON OPERATION OF SUBMARINE DIESEL ENGINES.

By Lieut. Comdr. Frederick C. Sherman, U. S. Navy, Member.

The following remarks are random notes made while operating under war conditions submarine Diesel engines of 440 H.P., 4-cycle, 6-cylinder type, manufactured by the New London Ship and Engine Co., and installed on the O-class of submarines. As this type of engine has become almost the standard production of that Company and has been installed on a number of our submarines with only variations as to size and number of cylinders, it is believed that this information obtained from early experience with these engines under strenuous operating conditions will be of value to others taking up the operation of the same type engine. In addition, it may suggest ideas which will be of value in operating Diesel engines of other types. This article is somewhat of a continuation of an article by the writer on the same subject published in the Journal of November, 1917.

BEARING TROUBLE.

The O-class of submarines equipped with Nelseco Engines of the 4-cycle type when first placed in commission had considerable trouble with burned out and wiped crank-shaft and crank-pin bearings. No direct cause of this could be discovered, as one or more bearings would go out simultaneously while lubrication was apparently sufficient, everything running normally, and bearing previously adjusted to proper clearance. To understand the lubrication system on these engines a brief description is as follows: The engines

are oiled by a forced lubrication system which comprises a motor-driven rotary oil pump taking oil from a sump or settling tank located in the bilge below the crank case and discharging through a cooler into a pipe with branches to each main bearing, from which the oil passes to the interior of the crank-shaft through the crank web to the crank-pin bearing; then up through the hollow connecting rod to the wrist pin bearing, whence it seeps out and drains by gravity to the crank case from which it further drains to the sump tank. In addition, a mechanical oiler is connected to each cylinder for cylinder wall lubrication, injecting the oil at four different points in each cylinder.

The circumstances of the bearing trouble were as follows: The first indication would be a knock from a crank-pin bearing with subsequent heating of the bearing. Upon opening the crank case, this bearing would be found to be burned out, its babbitt metal melted and run into the crank case. Upon test the bearing would appear to be getting lubricating oil from a good flow through the oil hole in the crank-pin. A visual examination without breaking down of the adjacent main bearings would show no sign of trouble. But upon putting in a new crank-pin bearing, after running an hour or so the bearing would go again. Sometimes the main bearings would be burned out also, but usually the procedure was as above. However, it was found after frequent recurrences of this trouble that even though the main bearings were apparently all right and showed no signs of having been overheated, if they were disassembled and examined they would be found to be slightly wiped and perhaps one of them with the oil hole through the babbitt plugged, so that the crank-pin was only getting oil from one side. This would show a fairly good flow of oil from the crank-pin when stopped but would not give sufficient oil for good lubrication when running. What made this bearing trouble so inexplicable was the fact that bearings would burn out when they had all been carefully ad-

justed to the proper clearance. It would have been perfectly understandable if the bearings had had too much or too little clearance, for too much would cause the oil to wash out and prevent bearings further on from getting sufficient oil, and too little clearance would cause the bearing to run hot and the babbitt metal to flow. But these bearings which were burning out were ones which had been adjusted with extreme care, and they were burning out too regularly to be from careless or faulty adjustment.

The problem then became one of discovering why the main bearings were wiping and shutting off the flow of oil to the crank-pin. In searching for the answer to this question the following theory was evolved:

Frequently when making examination as a result of this trouble, one or more of the oil pipes to the main bearings, or the radial hole in the crank web would be found plugged up with a sticky mass of about the consistency and appearance of coal tar. This occurred in spite of the fact that the lubrication system had been previously thoroughly cleaned out and the fine mesh strainers in the system showed no signs of any foreign matter being caught there. Further investigation showed the inside of the pistons near the top and around the wrist pin coated with carbon of somewhat the appearance of the gummy mass which had plugged the oil holes. This carbon was in an excessive amount and was apparently in all pistons in about equal amount. One piston which was removed as a result of a piston seizure showed heavy carbon deposits inside and also a smaller amount of carbon around the wiper and piston rings on the inside of the piston. Assuming that the carbon forming on the inside of the pistons and that in the lubricating oil pipes was the same, it became necessary to trace how it was formed and how it could get into the lubricating system and through the strainers.

The theory was then evolved that the lubricating oil which seeped out the ends of the wrist pin bearing and drained to

the crank case was being splashed onto the hot piston and cylinder walls and there being evaporated or imperfectly burned, leaving behind a heavy residue. This residue, being hot and still fluid, would be partly scraped off into the crank case and the other part of it would be worked up into the piston rings. This latter part would gradually work on through the rings and then on into the cylinders where it would eventually be burned completely or left as a deposit on the exhaust passages. If sufficient of this residue should be caught in the piston rings at one time, it might be a contributory cause of a piston seizure. As a matter of fact, a number of these did occur coincidently with the bearing trouble. The part of the residue which was scraped off into the crank case, having considerable temperature and fluidity, would flow with the oil through the sump tank and strainers and pump until it came to the cooler. Here the heavy tarry particles would be cooled sufficiently to begin to congeal. But they would flow along with the oil until they struck a restriction or smaller passage such as the pipes to each main bearing or the holes in the crank webs, where the particles would lodge and gradually collect until the oil passage was shut off altogether and that bearing would lose its oil, resulting in the bearing troubles mentioned in the beginning of this paper.

The question then was how to prevent this action, as it was not practicable or desirable to install splash plates to prevent the oil from splashing on the cylinder walls and piston. As it was impracticable to prevent some of the oil from splashing, it was decided to reduce the oil pressure and thus reduce the amount of oil splashed. The pumps had previously been carrying an oil pressure of 14 pounds per square inch (above atmosphere), whereas by design 5 pounds per square inch was sufficient for proper lubrication. But as is usual with bearing trouble, the policy had been to "give her more oil" and the pressure had been increased with only more disastrous results. So the average oil pump pressure was re-

duced to 7 pounds, and the machinists on watch had orders not to let it go over 8 pounds. In addition, the cylinder lubrication from the mechanical oilers which had been running about 18 to 20 drops per minute was cut to 4 drops per minute. In addition, after each long run, the oil passages were thoroughly cleaned out, especially those in the crankshaft webs. A small amount of the tarry mass was discovered to have collected each time, but not sufficient to cause trouble. With this treatment, practically all bearing trouble disappeared for a while. It reappeared again, however, on a trans-Atlantic trip of the O-7. The cause appeared mysterious at first and it was feared that something was wrong with the above theory. But the new trouble was soon located on investigation. It was found that the lubricating pump was frequently getting air bound and losing its suction, resulting in the engine more or less frequently running for short intervals without any lubrication. This resulted in the main bearings wiping sufficiently to plug the oil holes and subsequent running burned out the bearings. Nearly all bearings on one engine were burned out at sea from this cause on the return trip. The pump was found to be getting air bound from air leaks in the system on the suction side of the pump. Some trouble was experienced in definitely locating all these air leaks, but when they were all found and remedied the bearing trouble ceased to exist.

Some vessels of this class had piston seizures which were probably caused primarily by the same cause as above. The wrist-pin bearings would heat up, being short of oil from clogging in the system and the heat would be transferred to the piston walls. This would cause excessive expansion of the piston and cause it to stick and seize in the cylinder. The oil residue left on the cylinder walls from its partial burning would be a contributory cause of this result. The treatment as above to eliminate bearing trouble also ended the piston seizures.

This information sums up as follows:

(*a*) Burned out main and crank-pin bearings; piston seizures.

(1) Caused by too high lubricating oil pressure and subsequent excessive splash on hot piston and cylinder walls, resulting in gummy residue mixing with lubricating oil.

(*b*) Remedies.

(1) Reduce lubricating oil pressure to slight margin above theoretical requirements, viz., 7 pounds.

(2) Reduce cylinder wall lubrication to minimum, about 4 drops per minute.

(3) Clean oil passages to all bearings and in hollow crank-shaft after each long run.

(4) Prevent air leaks on suction side of pump, so that pump will not get air bound and lose suction.

(5) Keep bearings adjusted to proper clearance.

ECONOMY OF LUBRICATING OIL.*

USE OF LUBRICATING OIL AS FUEL.

The following procedure has been tried out on the U. S. S. O-7 but is not advised as good practice for usual routine unless in case of emergency.

The O-7 on a trip across the Atlantic to the Azores was running a very high consumption of lubricating oil, giving grave concern over whether the supply would last for the trip. As it was not possible to stop to go over the system to discover whether the bearings had the proper clearances and whether or not this was the cause of the high consumption, as

* In the opinion of the Editor the writer was saved from very disastrous results by prevailing conditions; the practice outlined has nothing to recommend it, but rather should serve as a bad example. Discussion of this article is invited.

no external leaks to the bilge could be found, and as it was imperative to reduce the consumption, the experiment was tried of mixing fresh water with the oil so that half of the expenditure would be water instead of oil. This worked out very satisfactorily so far as could be discovered on a 14-day run. The fresh water, about 10 to 15 gallons, was simply added to the settling tank every four hours. This amount would churn up with the oil and form a good emulsion. Once every twenty-four hours sufficient fresh oil would be added to bring the level in the settling tank to the proper point. By the use of fresh water, the amount of oil needed to be added each day was cut about in half. The mixture of oil and fresh water formed an emulsion which was a sufficient lubricant and the water was evaporated off upon striking the hot parts of the system, thus reducing the amount of lubricating oil burned. The only loss of lubricating oil, it must be understood, in a system similar to this one is either from leaks to bilge or burning of the oil on the cylinders and other hot parts of the engine. By allowing the fresh water to be "burned" or evaporated in place of oil, considerable saving resulted. Great care must be observed, however, to see that fresh water and not salt is used as salt water will leave a heavy salty deposit which will ruin the engines if continued. From using fresh water as above, however, for over 10 days' continuous running, no harmful results were observed, and a big saving of lubricating oil was accomplished.

The use of lubricating oil as fuel came about as a result of the above economy in lubricating oil. Several days before the end of the 14-day trip it was foreseen that fuel oil was going to be very short at the end of the run and everything possible was done to economize. But the evaporator had been run almost constantly to furnish fresh water for the crew for bathing and washing as well as for diluting the lubricating oil, which all resulted in increased fuel consumption. It is also believed that the heavy consumption was par-

tially caused by extra power used in driving line shafts which had been sprung and propellers which had been damaged by striking part of the superstructure which had been previously carried away by heavy seas. Anyway, every drop of fuel was used when the O-7 was about 12 hours out from Punta Delgada, Azores. Due to the economy in *lubricating oil*, there was a surplus left of about 400 gallons. To burn it in the engines as fuel was the problem, as the engines were designed to burn a lighter oil, something between boiler fuel and the lighter distillates. It was first attempted by mixing 10 per cent of alcohol (which was kept in the vessel for use in torpedoes) with lubricating oil. It was feared that the alcohol might not mix thoroughly and that if the cylinders received a quantity of pure alcohol, a disastrous explosion might result. However, the mixture was made in buckets and thoroughly stirred and then poured into the gravity feed tanks. After a few splutterings and misfires, the engines started off and appeared to run all right. It worked first rate and filled us with joy that we would be able to make port without assistance, although it kept the crew busy mixing alcohol and lubricating oil and pouring it into the tank. All went well for about 4 hours, when the alcohol gave out and the destination about 8 hours away. Attempt was made to burn the lubricating oil without alcohol, but it would not seem to fire. However, after many attempts and with the storage battery getting low from frequent attempts to start the engine, it was found that if the engine circulating water was choked down enough to allow the cylinders to warm up to a temperature of about 160 degrees F. the lubricating oil would burn all right.

The reason for this is probably two-fold. It is believed that the rise in temperature of circulating water resulted in somewhat increasing the temperature of compression, and also that the mixing chamber of the spray valve became hotter from the increase in temperature of the circulating water

and that this resulted in better flow of the lubricating oil through the spray nozzles and consequently a finer spray. Anyway, following this procedure good combustion was obtained and for about 8 hours no further trouble burning straight lubricating oil for fuel was experienced. The vessel reached the destination with both engines running and a supply of lubricating oil sufficient to run for quite a number of hours more.

However, the above practice is uneconomical and probably results in excessive carbonization of cylinders, imperfect combustion, and might result in burning spray valve nozzles and in damage to fuel oil pump. So it is not advocated as standard practice unless in an emergency to reach port with all fuel exhausted. The method used in burning it, however, is a good thing to know in case an emergency demands its use.

The mixing of water with lubricating oil for lubricating purposes is not advocated as standard practice as it is not believed to be necessary under proper conditions and might result in corrosion of journals or bearings if carried out for a long time. The possibility of its use, however, is a good thing to bear in mind if ever caught out at sea with lubricating oil running low and no other way to reach port.

TEST OF TWO-TON CLOTHEL REFRIGERATING MACHINE.

By M. C. Stuart, Associate.

There was conducted recently at the U. S. Naval Engineering Experiment Station, Annapolis, Md., a test of a two-ton refrigerating machine manufactured by the Clothel Co., New York City. Inasmuch as Refrigerating Machines of this type in smaller sizes are in use in the Naval Service, it is believed that a description of the two-ton machine and a brief summary of the results obtained on the test would be of interest.

The refrigerant used in the machine is Ethyl-Chloride, C_2H_5Cl, a neutral chemical having a boiling point of 54.5 degrees F. at atmospheric pressure. The unit consists of a motor-driven rotary compressor, a condenser, separator, expansion trap and brine cooler. The motor-driven compressor is shown in Fig. 1. The motor drives the compressor through spur gears having a speed reduction of 3.75 to 1. Small rotary pumps for circulating the brine and the condensing water are driven from either side of a spur gear which is driven in turn by the large gear. The construction of the rotary compressor is shown in detail in Fig. 2. The rotor is located eccentrically in the cylinder which is bored elliptically on a special machine. The top of the rotor makes contact with the top of the cylinder, thereby forming a seal between the suction and pressure sides of the cylinder. The blades are fitted into four slots milled radially in the rotor and into the outer edge of the blades are fitted half round packing strips which are machined to conform to the inside of the cylinder. The blades and packing strips are held out by spacing pins which pass through the center of the shaft. The seal between the blade and cylinder wall is therefore positive and contact between blade and cylinder wall does not depend

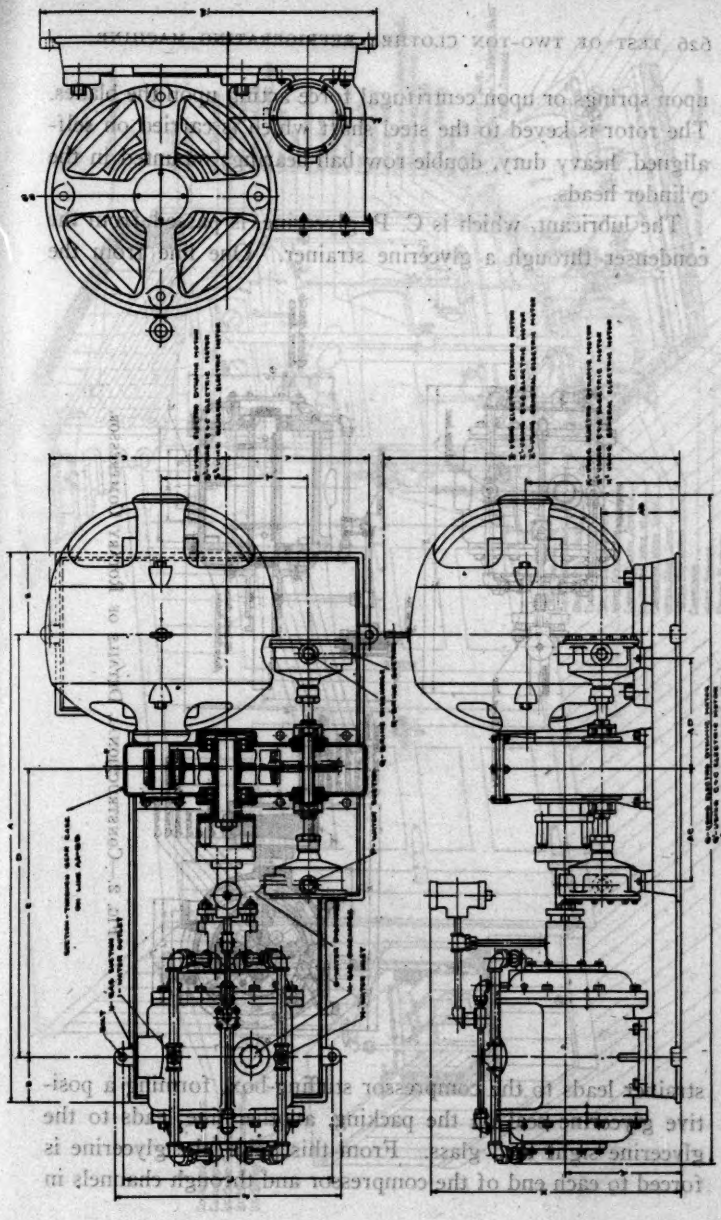


FIG. 1.—MOTOR-DRIVEN ROTARY COMPRESSOR.

upon springs or upon centrifugal force acting upon the blades. The rotor is keyed to the steel shaft which is carried on self-aligned, heavy duty, double-row ball-bearings mounted in the cylinder heads.

The lubricant, which is C. P. glycerine, is passed from the condenser through a glycerine strainer. One line from the

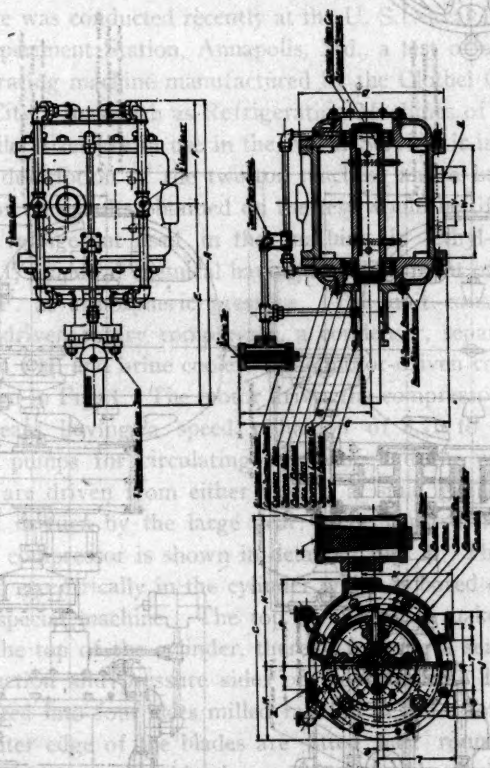


FIG. 2.—CONSTRUCTIONAL DETAILS OF ROTARY COMPRESSOR.

strainer leads to the compressor stuffing-box, forming a positive glycerine seal on the packing, another line leads to the glycerine sight feed glass. From this point, the glycerine is forced to each end of the compressor and through channels in

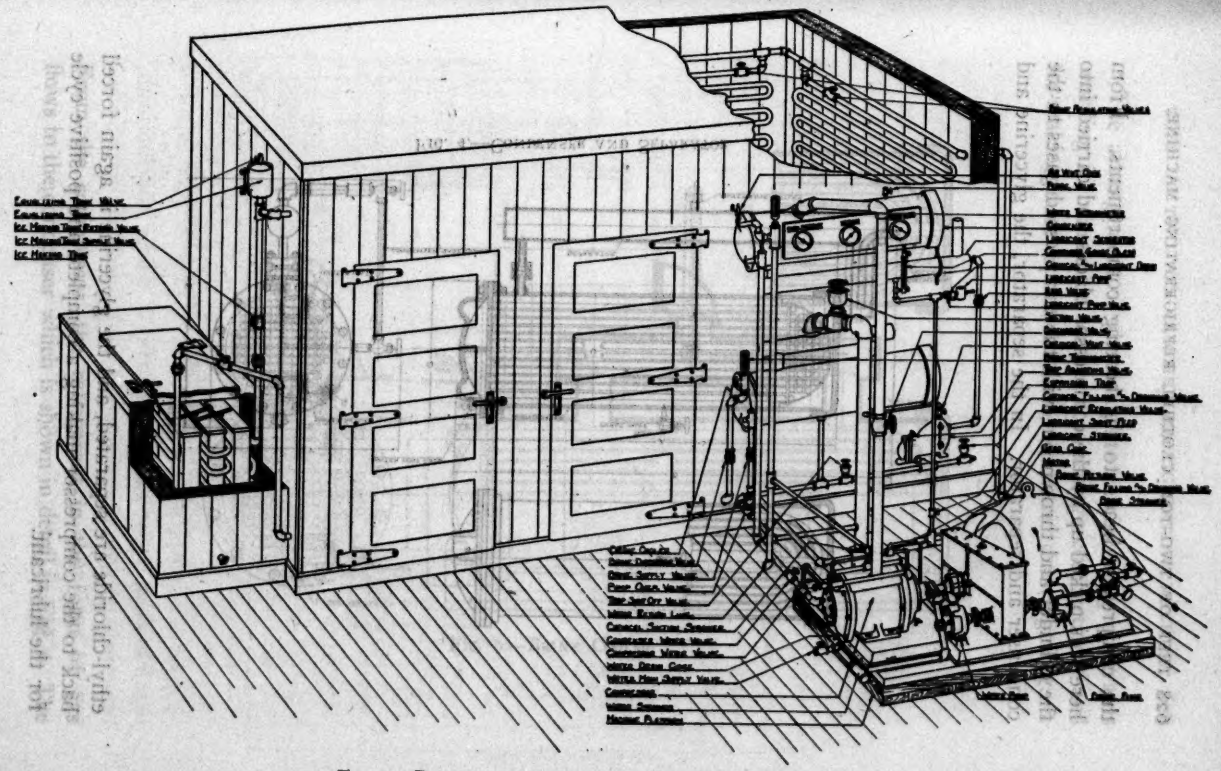


FIG. 3.—PERSPECTIVE OF COMPLETE TWO-TON CLOTHEL UNIT.

the compressor heads to the bearing compartments. From here it is picked up by the compressor blades and carried into the cylinder and thrown out with the compressed gases to the condenser and separator. In the separator, the glycerine and

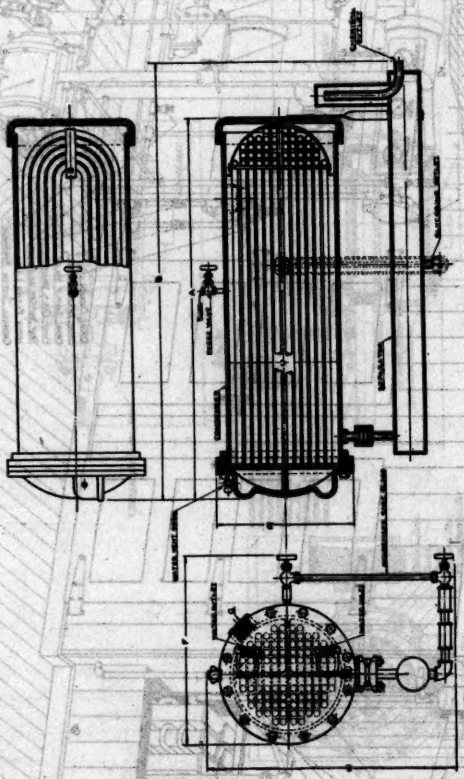


FIG. 4.—CONDENSER AND SEPARATOR.

ethyl-chloride are separated, and the glycerine is again forced back to the compressor making a complete and positive cycle for the lubricant.

The arrangement of the complete refrigerating apparatus working in connection with a cold-storage compartment and ice-making tank is shown in the isometric drawing, Fig. 3.

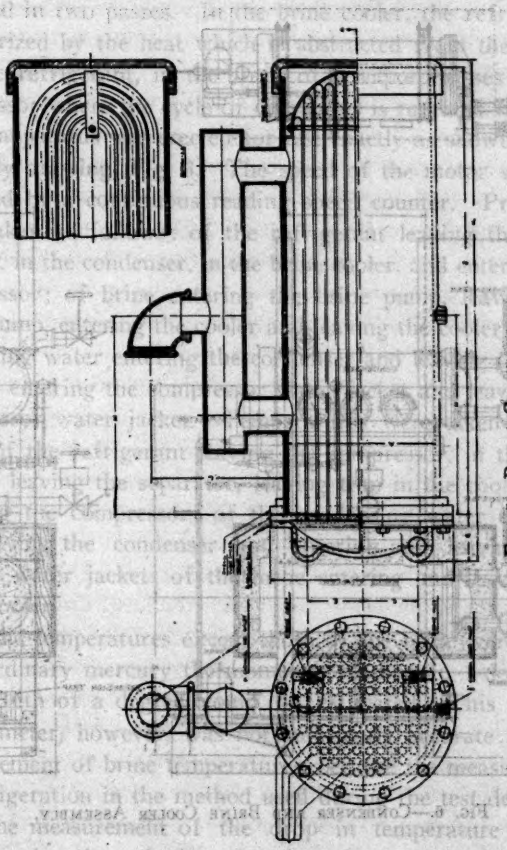


FIG. 5.—BRINE COOLER.

From the compressor, the refrigerant in the form of gas flows to the condenser which is shown in detail in Fig. 4. The

condensing element consists of U-tubes arranged in two passes with condensing water flowing through the tubes. After being condensed, the liquid refrigerant, together with

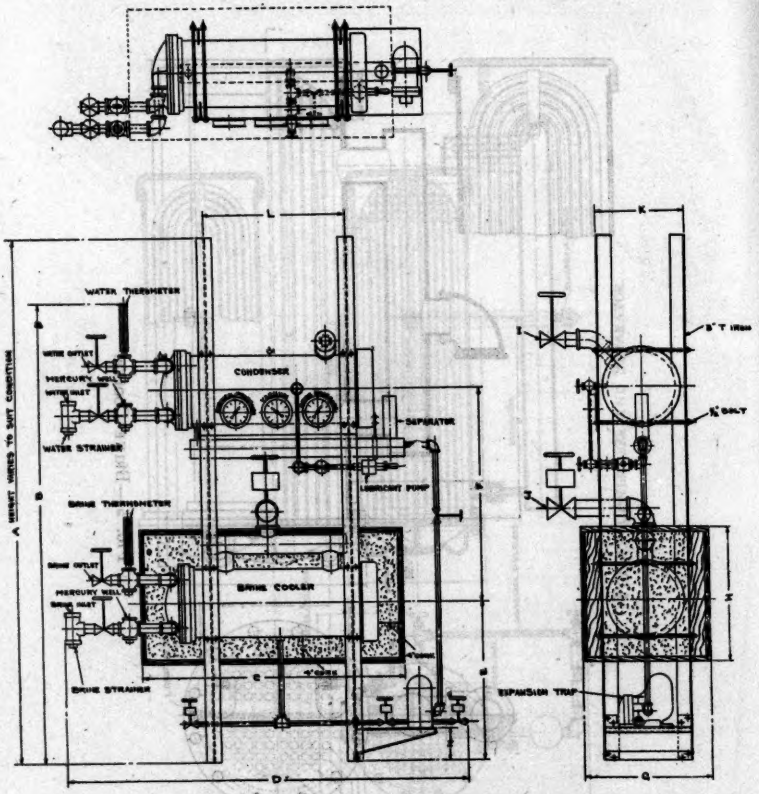


FIG. 6.—CONDENSER AND BRINE COOLER ASSEMBLY.

the lubricant, falls into the separator where the lubricant, being heavier than the refrigerant, is drained back to the compressor and the liquid refrigerant is lead to the expansion trap as shown in Fig. 3. After expansion through the valve

of the expansion trap, the refrigerant passes to the brine cooler which is shown in detail in Fig. 5. The construction of the brine cooler is similar to that of the condenser. The refrigerant is in the shell and the brine passes through U-tubes arranged in two passes. In the brine cooler, the refrigerant is vaporized by the heat which is abstracted from the brine, and the refrigerant, in the form of a vapor, passes to the compressor where the cycle of operations is repeated.

The apparatus was erected for test exactly as shown in the assembly drawing, Fig. 3. The speed of the motor was determined by a continuous reading speed counter. Pressures were taken as follows: of the refrigerant leaving the compressor, in the condenser, in the brine cooler, and entering the compressor; of brine entering the brine pump, leaving the brine pump, entering the cooler and leaving the cooler; of the circulating water entering the condenser and leaving the condenser; entering the compressor water jacket and leaving the compressor water jacket. Temperatures were taken as follows: of the refrigerant leaving the compressor, in the condenser, leaving the separator, leaving trap in the cooler, and entering the compressor; of the condensing water entering and leaving the condenser and entering and leaving compressor water jacket; of the brine entering and leaving the brine cooler.

All the temperatures except those of the brine were taken with ordinary mercury thermometers reading to 1-degree in which 10th of a degree could be estimated. This type of thermometer, however, was not sufficiently accurate for the measurement of brine temperatures, because the measurement of refrigeration in the method used during the test depended upon the measurement of the drop in temperature of the brine passing through the cooler, and inasmuch as this drop in temperature would usually amount to only two or three degrees, thermometers in which 10ths of a degree must be estimated were not sufficiently accurate. For the purpose of

measuring inlet and outlet brine temperature, special thermometers were used having graduations to 10ths of a degree and in which 100ths of a degree could be estimated. The thermometers were read by means of telescopes and by interchanging the inlet and outlet thermometers several times during each run any possible error in the differential temperature between the inlet and outlet brine could be determined and eliminated. From the analysis of the brine temperature readings thus obtained, the average possible error in temperature difference was found to be less than 0.02 degree F.

The electrical input to the motor was measured by means of an ammeter in the armature circuit, an ammeter in the field circuit, a voltmeter connected across the armature, and a voltmeter connected across series and interpole fields. From these electrical readings, the output of the motor was determined by means of the stray power method.

Condenser circulating water and the cylinder jacket circulating water were weighed in tanks on platform scales. The amount of brine circulating through the brine cooler was measured by means of a calibrated Venturi meter which was located in the line between the brine pump and the brine cooler. This Venturi meter was calibrated by comparison with weighings of brine on calibrated scales. During the run the brine from the brine cooler was circulated through a brine heater, where by means of circulating water sufficient heat was added to bring the brine to the temperature desired for the run. From the brine heater the brine was discharged into a storage tank from which the brine pump took its suction. By this means a very constant brine temperature of any desired value could be obtained. The reading of a differential mercury manometer on the Venturi meter indicated the quantity of brine flow. During the calibration of the Venturi meter, the brine was discharged into tanks on scales mounted above the brine storage tank, and conditions of operation were kept the same as during the runs.

Runs were made with circulating water temperatures of approximately 65, 70, and 90 degrees F. With 65 degrees circulating water, 4 runs were made with outlet brine temperature of approximately zero, 10, 15 and 20 degrees F. With 70 degrees circulating water, runs were made with outlet brine temperatures of zero, 10, 15 and 20 degrees. With 90 degrees circulating water, runs were made with outlet brine temperatures of zero, 10, 15, 20, 30 and 35 degrees F. All runs were made at the rated speed of the machine. Runs were not started until the conditions became constant and each run was of a duration of one hour.

RESULTS OF TEST.

The principal results obtained on the test are given in Table I. The total refrigerating effect was determined from the heat given up by the brine in the brine cooler. In order to obtain the net available refrigerating effect, the amount of heat added to the brine by the brine circulating pump was subtracted from the total refrigerating effect. The heat given up by the brine in the brine cooler was computed from the product of quantity of brine circulated, drop in temperature of brine in passing through cooler, and specific heat of the brine. The value of specific heat of the brine was obtained from the Bureau of Standards Scientific Paper No. 135.

An inspection of the table of results shows that the refrigerating effect is increased with higher brine temperatures and lower circulating water temperatures. With a circulating water temperature of 70.1 degrees F., and a brine temperature of 14.57 degrees F. (which is practically the ice-making temperature) the net refrigerating effect was 2.13 tons per day.

TABLE I.

Item No.	Item	Unit	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Run number.	–	1	2	3	4	5	6	7	8	9	10	11	12	13	14
2	Speed of motor.	R. P. M.	837	849	807	815	809	831	836	840	833	843	842	846	846	844
3	Speed of compressor.	R. P. M.	223	226	215	217	215	221	222	223	222	224	224	225	225	225
4	Temperature of circulating water.	Deg. F.	89.7	89.9	90.0	90.0	89.9	89.7	70.1	64.1	64.9	65.2	64.5	70.5	70.1	70.3
5	Temperature of brine outlet.	Deg. F.	(–)0.15	10.00	14.63	20.19	30.14	35.05	9.66	(–)0.01	15.21	9.69	19.90	20.16	14.57	(–)0.05
6	Power to motor.	H. P.	9.01	10.05	8.85	9.35	9.86	10.01	7.57	7.25	8.03	7.39	7.95	8.36	8.22	7.90
7	Vapor pressure in condenser.	Lbs. per sq. in. gage.	33.2	37.7	33.3	35.7	38.8	37.8	21.0	17.0	21.1	18.9	21.3	24.9	23.6	22.9
8	Temperature of Ethyl-Chloride in condenser.	Deg. F.	98.2	100.8	103.8	105.8	109.0	112.7	84.1	76.2	83.0	79.5	83.1	88.3	86.7	83.2
9	Vacuum in brine cooler.	Inches mercury.	23.4	21.7	20.8	19.7	17.3	15.9	22.0	23.6	20.8	21.8	19.7	19.6	20.9	23.6
10	Temperature of refrigerant in brine cooler.	Deg. F.	(–)8.5	(–)1.0	3.0	7.0	16.0	19.9	(–)2.0	(–)10.0	2.7	(–)1.9	7.0	7.0	3.0	(–)9.6
11	Brine circulated.	Lbs. per min.	213.2	213.7	202.1	202.3	198 8	204.0	208.0	211.3	206.5	213.0	210.4	211.7	209.4	211.7
12	Condensing water.	Lbs. per min.	109	108	100	104	98	91	100	100	98	100	99	98	95	92
13	Temperature drop of brine in cooler.	Deg. F.	1.75	2.30	2.94	3.11	3.79	4.26	2.72	2.18	3.14	2.70	3.38	3.32	3.06	2.10
14	Refrigerating effect, total.	Tons per day.	1.25	1.66	2.02	2.15	2.58	3.00	1.92	1.55	2.21	1.95	2.43	2.41	2.19	1.49
15	Refrigerating effect, net.	Tons per day, net.	1.18	1.59	1.96	2.09	2.52	2.94	1.86	1.48	2.14	1.88	2.36	2.34	2.13	1.42

CHARLES H. MANNING.

In the death, April 1, 1919, of Chief Engineer Charles H. Manning, U. S. Navy, retired, there passed away an officer whom the Navy of his day honored for his engineering genius, his sterling character, and his kindly and genial qualities which won men's friendship everywhere. Loyal, gallant, faithful in all things—thus he lived to honored age. And, in passing, he leaves noble memories to the engineering Navy of our day.

Charles Henry Manning was born in Baltimore, Md., on June 9, 1844. He was the son of Joseph Cogswell Manning and Rebecca Parkman Jarvis (Livermore) Manning, and came from old New England stock, having been the descendant in the ninth generation of William Manning, who settled in Cambridge, Mass., in 1634, and whose land there remained in the Manning family for more than two hundred and thirty years thereafter. In 1871, Captain Manning married Miss Fanny Bartlett, of Boston, the sister of Major-General William F. Bartlett, one of the most gallant men sent by Massachusetts to the Civil War.

Mannings' father was for many years a prominent iron merchant of Baltimore, owning and operating the Avalon Nail and Iron Works there. He received his early education in private schools in Baltimore and in the High School of Cambridge, Mass. In 1860, he entered the Lawrence Scientific School of Harvard University to study civil engineering. After the fall of Fort Sumter, he joined the drill club which guarded the State Arsenal at Cambridge, and later was offered a lieutenancy in a Massachusetts regiment, which, because of his youth, his father would not permit him to accept.

Owing to his father's business reverses brought on by the war, Manning returned to Baltimore in the autumn of 1861, and, following his natural bent, entered as an apprentice the marine engine works of Charles Reeder where, in working on

naval vessels, he met a number of their engineer officers. Contact with them gave his active energies a definite aim, and, as a result, he was appointed a Third Assistant Engineer in the Navy on February 19, 1863, having passed third in the class of sixteen of that date.

He was, however, to see relatively little service under fire, since Engineer-in-Chief Isherwood, recognizing his worth as a scientific observer, kept him closely occupied with the classic experiments on superheated steam in the *Adelaide* and other vessels, thus limiting his experience of actual naval war to some brief fighting in Hampton Roads and to passage in convoy of troops during the siege of Charleston.

He served on the *Adelaide* for two years, and left her in March, 1865, for the sloop-of-war *Dacotah* to which vessel he was attached until September, 1868, making in her the circuit of South America and cruising as far north as Panama. The outward passage was noteworthy for the company of the Peruvian ironclads *Independencia* and *Huascar* from Rio de Janeiro onward, since the latter vessel was to become memorable in naval history for her heroic fight in the subsequent war with Chile. The *Dacotah* was also at Valparaiso during the great earthquake of August, 1868, and the next day left for Africa, where 10,000 lives had been lost and the U. S. S. *Wateree*—an iron double ender—had been washed a mile inland and left there on an even keel.

From the *Dacotah*, Manning was ordered to the sloop-of-war *Seminole* which cruised on the home station, mainly in West Indian waters, until February, 1870, when she returned to New York with yellow fever on board, and was put out of commission. From September, 1875, to September, 1877, he served on the sloop-of-war *Swatara*, and from September, 1880, to August, 1882, on the President's Yacht, *Despatch*—in both cases on the home station. With the latter duty, his service at sea ended.

Owing to his marked ability, not only in engineering science but as an instructor, Manning's shore duty was passed wholly

at the Naval Academy, where he was stationed for five years beginning with September, 1870; and later for three years from September, 1877, onward. During the first of these tours of duty, he aided in organizing the course of instruction for Cadet Engineers at the Academy—in fact, as the subsequent experience of his students proved, his influence had a most marked and lasting effect on that course.

"This was the most valuable work I ever did," said the veteran engineer to the writer one evening long ago, as he reviewed the achievements of a life, strenuous always, and successful in so many fields. And, he might well say this, for the courses which he had so vital a part in founding constituted not only the first definite effort by any navy to train young men for its Engineer Corps, but formed as well the first technical school of mechanical engineering established in the United States. The work of Manning and his associates—Kafer, Tower, Kearney, and others—in this aided signally in the advancement of the sciences of marine and mechanical engineering.

The engineering course at Annapolis was established by Congress in 1864, but the project languished until 1871 when the first class of sixteen members was admitted to the Academy. Yearly thereafter, twenty-five cadets were appointed until 1882, when, in the full tide of its success, it was abolished by Act of Congress, and the Cadet Engineers then at the Academy were transferred as Cadet Midshipmen to the Line of the Navy.

The course met thus its sudden ending because of its very success, and that success was the result primarily of two conditions: first, its instructors were picked men, the ablest in the Engineer Corps of that day; second, its cadets were selected by competitive examinations, so severe eventually that most of the successful candidates came from colleges or universities.

The natural result of this system was the formation of a body of students who, in scientific ability, could not but be superior, as a whole, to the Cadet Midshipmen of that day,

who were then, as a rule, appointed by political influence. The contrast between the two courses was sharply shown when, in 1882, the Cadet Engineers were transferred to the corresponding classes of Cadet Midshipmen. In his work, "The Steam Navy of the United States," Captain Frank M. Bennett, U. S. Navy, says:

"A year after the exchange was made, we find that seven of the first ten members of the graduating class were former Cadet Engineers, and four of the six 'stars' of that class were engineers. * * * In the next class, the three leading members were former Cadet Engineers. * * * In the third class, after the amalgamation took place, * * * we find that thirteen of the first fifteen members, nine of the first ten, and all six of the 'stars' were former Cadet Engineers."

All navies were then, like our own, in a transition stage, passing slowly and reluctantly from sails to steam. The inevitable and sweeping progress of engineering in naval science was then far from being foreseen by even engineers themselves. It is not strange, then, that the great body of Line Officers, proud of the noble traditions of the days of sail, should have dreaded the effect of such a system of engineering education upon the prestige of their branch of the service, and so the change was made. Even that accomplished seaman, Captain "Jack" Philip, when asked why the course had been abolished, said frankly: "We had to do it. If we had not, the engineers would have crowded us off our ships." From the viewpoints of naval efficiency and of harmony within the Navy, it is regrettable that the effective solution of this vital problem—given by the Amalgamation Act of 1899—was not sooner found, and that engineering was not earlier made, as it should be always, one of the duties of the Line of the Navy.

In 1881, while attached to the *Despatch*, Manning served as a member of the first Advisory Board. This Board consisted of thirteen officers of the Line, Engineer Corps, and Construction Corps. The engineer members, in addition to Manning,

were Chief Engineers Benjamin F. Isherwood and Charles H. Loring. In one noteworthy step of the Board's action—the decision to build the hulls of the new vessels of steel—Manning cast the deciding vote, the Board standing 7 to 6, and he being the only engineer who, in the existing condition of steel-making in the United States, was willing to take the responsibility of voting for that metal.

Manning's service to his Corps, in seeking by all just means the rightful recognition of engineering, began early as was to be expected from his determined character. The Line and Staff feud of those old days was a relentless strife, the bitterness of which it is difficult to realize fully at this time. Two incidents, which Manning used to tell with a grim smile, show his boldness in forcing justice.

A bill had been rushed through, without due consideration, in the closing days of Congress, abolishing the grade of Third Assistant Engineer. If this measure had become a law, its effect would have been to drop summarily these officers from the navy, wherever they might be stationed, "from China to Peru," without even an allowance for traveling expenses to their homes. By unremitting effort, Manning, through a friend, brought the bill to the indignant attention of President Andrew Johnson on the last day of the latter's term of office. The President said: "This measure will become a law today, with or without my signature. There is but one thing to do," and, with his own hands, he tore the bill in two and threw the fragments into a fire blazing in an open grate in his office at the White House. With Congress on the verge of adjournment and the only legal copy of the bill thus destroyed, the threatened officers were saved to the Navy.

Shortly after, Manning was informed by the chairman of the Naval Committee of the Senate that that body would confirm appointments of certain engineer officers if their nominations were sent in at once by the Navy Department, but that a further delay would be dangerous. He called upon the Secretary of the Navy immediately and stated the case. The

Secretary, new to his office, sent for Admiral Porter, who, at that time, was virtually supreme in naval affairs. The Admiral, eager to defeat the nominations, advised against them; but Manning, in his presence, presented such a forcible argument to the Secretary that, despite the Admiral's opposition, the nominations were sent in and promptly confirmed. Only those familiar with naval customs can understand fully the boldness of a young officer of twenty-five in thus antagonizing the Admiral of the Navy. Such temerity could have, in those days, but one result—a prompt cruise to the torrid West Indies, to which Manning was shortly ordered.

It is pleasant to note that Admiral Porter, while a relentless enemy with an unfading memory, had a manly respect for a worthy foeman. Years after, recognizing Manning on the *Despatch*, he came to the engineer officer and entered into a long and pleasant conversation, as if there never had been war between them.

In May, 1884, Manning was placed on the retired list of the Navy, owing to a partial loss of hearing, due, as the medical board reported, to exposure "in the line of duty." The retirement of such an officer, otherwise in the full vigor of manhood, was a most serious loss to his Corps and the Navy, a view which Chief Engineer Isherwood expressed in an appreciative letter to him, and which Rear-Admiral John L. Worden, who had commanded the *Monitor* in her engagements with the *Merrimac*, and who was then the president of the Retiring Board, also held, since he said to Manning: "I would rather see any other man than you in your Corps go."

In August, 1882, Manning was granted a year's leave of absence after twelve years of continuous duty. This leave was given that he might become Mechanical Engineer of the Amoskeag Manufacturing Company, of Manchester, N. H. Subsequently, he became General Superintendent of this company, remaining as such until 1913 when he retired and opened offices as a Consulting Engineer.

The Amoskeag Company operated the largest cotton mills in the world, its land and buildings extending in an almost unbroken line on both sides of the Merrimac River for a mile and a half. As superintendent, Captain Manning had charge of the power plant and the buildings and grounds, and in addition was the architect and builder of new mills there, including the latest, the Coolidge Mill, erected during recent years. The output of these mills is about a million yards of cloth a day. Under his administration, the steam power plant grew from one of 870 square feet of grate surface burning about 400 tons of coal per week, to one of 5,800 square feet, consuming 3,000 tons.

These mills show throughout the traces of Captain Manning's ability as an engineer and organizer. In the beginning of his service, he re-assembled the boiler plant after a plan striking in its boldness. The widely scattered units were gathered into groups near the coal pile, a steam pipe was laid across the river, and, in one case, steam was led through a pipe nearly half a mile long. Then, he designed the Manning vertical water-tube boiler, which is used not only in the Amoskeag Mills but very largely in textile manufacturing in New England.

In 1885, he was an engineering pioneer in designing and building at the Amoskeag Mills the first large installation (2,000 horsepower) of water turbines on a horizontal shaft. The fall of water was 47 feet and critics claimed that the sidewise thrust on the wheels would affect their operation. They, however, ran smoothly from the beginning. In 1891, a flywheel, 30 feet in diameter and running at 60 revolutions per minute, burst in one of these mills, the cause being a defective casting. Manning replaced it with his historic 30-ft. "wooden flywheel," an iron wheel with a rim built almost wholly of wood. The rim has a face of 108¼ inches and a thickness of 12 inches, and was made up of forty rings of ash.

Manning's service during the Spanish-American War proved the sterling quality of his patriotism. It was known to all

well-informed officers that the naval fighting in that war could be but brief and relatively unimportant, since our force on the sea was overwhelmingly superior to that of Spain. Manning was then fifty-four years of age, his business responsibilities were great, and he had the strongest political and naval influence, since both the Secretary of the Navy and the Engineers-in-Chief were his personal friends.

In these conditions, many retired officers of his age would have been tempted to seek assignments to relatively light inspection duty near their homes. Not so with Manning. There was important work to be done at the Key West Naval Station, in the repair of the machinery of the many warships which gathered there. Owing to the torrid climate, there was no more unpleasant shore duty for a naval officer. But, when Manning was asked to go there as Chief Engineer, he went without question and spent the summer in the stifling heat, glad to serve the flag again.

Years ago, in correspondence with the writer, Rear Admiral Melville, formerly Engineer-in-Chief of the Navy, said of Manning's work there:

"How fast the men of the old Engineer Corps are fading! There are left now but few of that bright galaxy—Kafer, Manning, Thurston, West, and a half score of others—who established the course for cadet engineers. To my mind, the ablest and most level-headed of them all was Manning. He was big in every way—in build and brain and heart.

"During the Spanish-American War the Navy Department was disturbed by the unusual number of ships which were laid up for repairs at Key West. For various reasons the situation at that station was difficult to handle. As engineer-in-chief, I tried several engineer officers there, giving them an abundance of tools and material, but the ships still lingered. Finally, I sent Manning there and the atmosphere of delay cleared quickly. He put no extra polish or finish on the work, but all that tended to efficiency of the machinery was done, and done promptly, and, through his tact and energy, the ships were

soon despatched to their stations on the southern side of the island of Cuba."

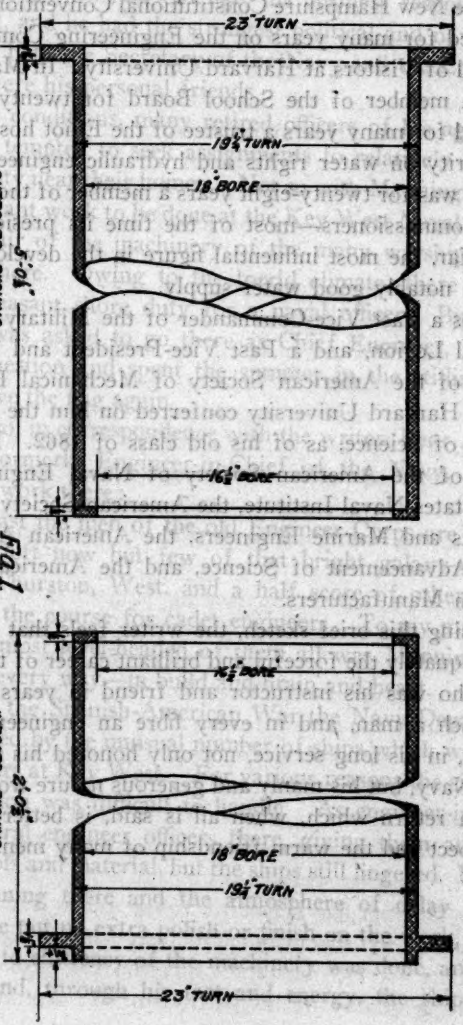
Captain Manning was active in civic duties. He was a delegate to the New Hampshire Constitutional Convention of 1886, and served for many years on the Engineering Committee of the Board of Visitors at Harvard University. In Manchester, he was a member of the School Board for twenty years or more, and for many years a trustee of the Elliot hospital. As an authority on water rights and hydraulic engineering generally, he was for twenty-eight years a member of the Board of Water Commissioners—most of the time its president—and was, by far, the most influential figure in the development of the city's notably good water supply.

He was a Past Vice-Commander of the Military Order of the Loyal Legion, and a Past Vice-President and Honorary Member of the American Society of Mechanical Engineers. In 1895, Harvard University conferred on him the degree of Bachelor of Science, as of his old class of 1862. He was a member of the American Society of Naval Engineers, the United States Naval Institute, the American Society of Naval Architects and Marine Engineers, the American Association for the Advancement of Science, and the American Society of Cotton Manufacturers.

In closing this brief sketch, the writer feels that it records but inadequately the forceful and brilliant career of the gallant officer who was his instructor and friend in years gone by. Every inch a man, and in every fibre an engineer, Captain Manning, in his long service, not only honored his profession and the Navy, but his manly and generous nature won for him as well a return which, when all is said, is better still—the deep respect and the warm friendship of many men.

PROBLEM CORNER.

Solutions of previous problems.



Problem No. 1. See Fig. 1.

Problem No. 2. No solution submitted.

Problem No. 3. The moment of the circular segment about the y axis, see Fig. 2, is

$$M = 2\int_{R\cos\theta}^{R} xy\ dx = 2\int_{R\cos\theta}^{R} x\sqrt{R^2 - x^2}\ dx = \tfrac{2}{3} R^3 \sin^3\theta.$$

This moment M is maximum when $\frac{dM}{d\theta} = 0$ or when $\frac{d}{d\theta}(\frac{2}{3} R^3 - \sin^3\theta) = 2 R^3 \sin^3\theta \cos\theta = 0$, this occurs when $\sin\theta = 1$ or $\theta = 90°$. The counterbalance of maximum effect is therefore a semicircle.

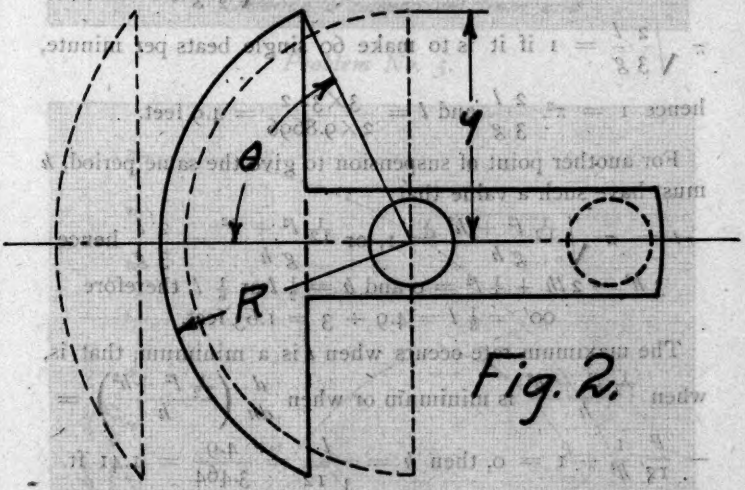


Fig. 2.

Since $M = \frac{2}{3} R^3 \sin^3\theta$ and $\sin\theta = \frac{y}{R}$, $M = \frac{2}{3} y^3$, which is to say, all segments having the same center and the same breadth have the same moment.

From a practical standpoint the semicircular counterbalance is too heavy and interferes with machining when forged on. The thickness of the crank webs determines the thickness of the counterbalance. The thickness of the

counterbalance and its maximum radius being determined, its breadth and distance from the axis can be computed from the expression for M.

Problem No. 4.

If a rod be suspended from one of its points the time of a single beat is $t = \pi \sqrt{\frac{k^2 + h^2}{g\,h}}$, k being the radius of gyration about the center of gravity and h the distance of the point of support from the center of gravity.

Suspended from one end $t = \pi \sqrt{\frac{\frac{1}{12} l^2 + \frac{1}{4} l^2}{\frac{1}{2} g\, l}} =$

$\pi \sqrt{\frac{2}{3} \frac{l}{g}} = 1$ if it is to make 60 single beats per minute,

hence $1 = \pi^2 . \frac{2}{3} \frac{l}{g}$ and $l = \frac{3 \times 32.2}{2 \times 9.8696} = 4.9$ feet.

For another point of suspension to give the same period, h must have such a value that

$$t = \pi \sqrt{\frac{\frac{1}{12} l^2 + h^2}{g\,h}} = 1, \text{ or } \frac{\frac{1}{12} l^2 + h^2}{g\,h} = \frac{2}{3} \frac{l}{g} \text{ hence}$$

$$3\,h^2 - 2\,lh + \tfrac{1}{4} l^2 = 0 \text{ and } h = \tfrac{1}{2} l \text{ or } \tfrac{1}{6} l, \text{ therefore}$$

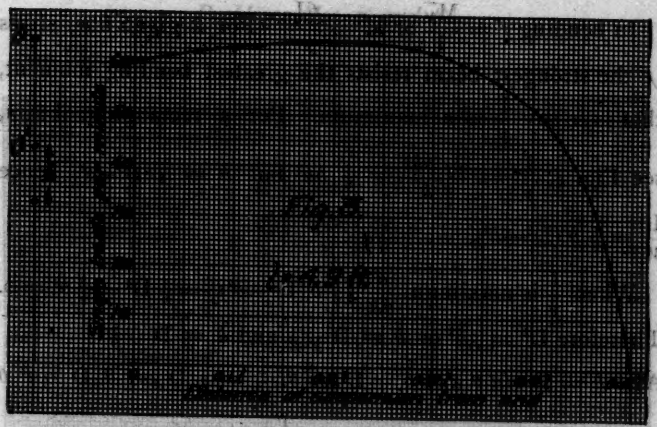
$$oo' = \tfrac{1}{3} l = 4.9 \div 3 = 1.63 \text{ feet.}$$

The maximum rate occurs when t is a minimum, that is, when $\frac{\frac{1}{12} l^2 + h^2}{h}$ is minimum or when $\frac{d}{dh}\left(\frac{\frac{1}{12} l^2 + h^2}{h}\right) =$

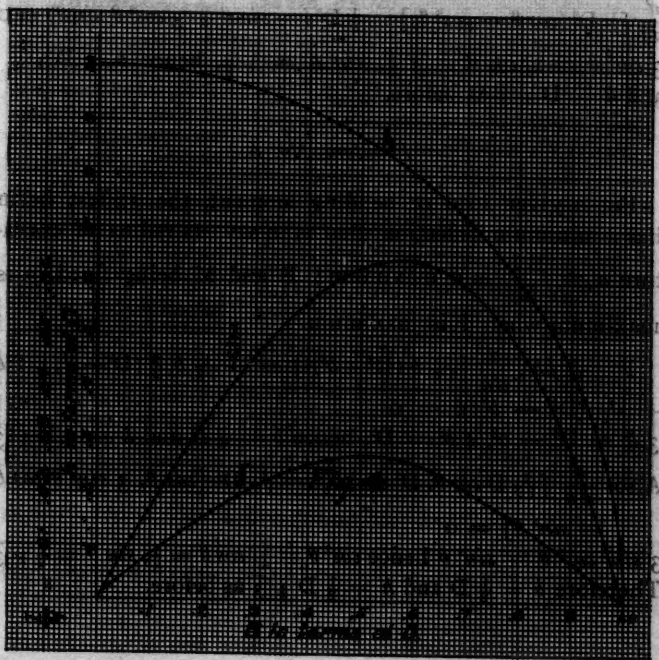
$-\frac{l^2}{12} \cdot \frac{1}{h^2} + 1 = 0$, then $h = \frac{l}{\sqrt{12}} = \frac{4.9}{3.464} = 1.41$ ft.

the corresponding rate is $\frac{1}{t} = \frac{1}{\pi \sqrt{\frac{\frac{1}{12} l^2 + \frac{1}{12} l^2}{g \frac{l}{\sqrt{12}}}}}$

or $\frac{1}{t^2} = \frac{6g}{\pi^2 l \sqrt{12}}$ or $\frac{1}{t} = 1.08$ beats per second or 64.8 beats per minute. See Fig. 3.



Problem No. 5.



In bending $f = \frac{My}{I}$ or $M = \frac{fI}{y}$. For a given fiber stress f, the strongest beam resists the greatest bending moment, that is to say $\frac{I}{y}$ is a maximum. For a rectangular beam, see Fig. 4, $\frac{I}{y} = \frac{\frac{1}{12} bh^3}{\frac{1}{2} h} = \frac{1}{6} bh^2$ but $h = \sqrt{D^2 - b^2}$, hence $\frac{I}{y} = \frac{1}{6} b (D^2 - b^2)$.

When $\frac{I}{y}$ is maximum $\frac{d}{dh} [\frac{1}{6} b (D^2 - b^2)] = \frac{1}{6} D^2 - \frac{3}{6} b^2 = 0$. Therefore $D^2 = 3b^2$ or $b = D \sqrt{\frac{1}{3}}$ and $h = D \sqrt{\frac{2}{3}}$

Also $h = D \sin \theta$ and $b = D \cos \theta$, $\frac{I}{y} = \frac{1}{6} D \cos \theta \, D \sin^2 \theta$ $= \frac{1}{6} D^3 (\cos \theta - \cos^3 \theta)$. When $\frac{I}{y}$ is maximum

$\frac{d}{d\theta} [\frac{1}{6} D^3 (\cos \theta - \cos^3 \theta)] = \frac{1}{6} D^3 (-\sin \theta + 3 \cos^2 \theta \sin \theta) = 0$

$3 \cos^2 \theta = 1$, $\cos \theta = \sqrt{\frac{1}{3}}$, $\sin \theta = \sqrt{\frac{2}{3}}$, hence $b = D \sqrt{\frac{1}{3}}$ and $h = D \sqrt{\frac{2}{3}}$ as before.

Problem No. 6.

For a given load or bending moment, the stiffest beam has a minimum deflection, that is to say, its radius of curvature $\rho = \frac{EI}{M}$ is a maximum; E and M being fixed, ρ is maximum when I is maximum.

$I = \frac{1}{12} bh^3$, $\frac{d}{dh} [\frac{1}{12} b (D^2 - b^2)^{\frac{3}{2}}] = -\frac{1}{12} b \cdot \frac{3}{2} (D^2 - b^2)^{\frac{1}{2}} \cdot 2b$ $+ \frac{1}{12} (D^2 - b^2)^{\frac{3}{2}} = 0$

$3b^2 = D^2 - b^2$, $4b^2 = D^2$, hence $b = \frac{1}{2} D$ and $h = \frac{1}{2} D \sqrt{3}$

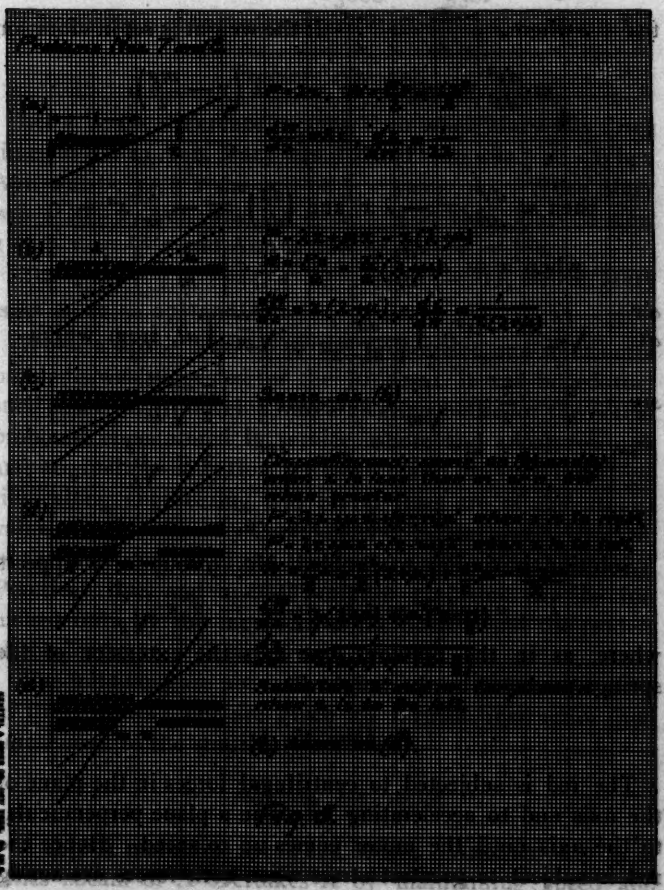
Also $\frac{d}{d\theta} [\frac{1}{12} D \cos \theta . D^3 \sin^3 \theta] = \frac{1}{12} D^4 [\cos \theta . 3 \sin^2 \theta \cos \theta$ $- \sin^4 \theta] = 0$

$3 \sin^2 \cos^2 \theta = \sin^4 \theta$ hence $\cos^2 \theta = \frac{1}{4}$, $\cos \theta = \frac{1}{2}$, $\sin \theta = \frac{1}{2} \sqrt{3}$

Therefore $b = \frac{1}{2} D$ and $h = \frac{1}{2} D \sqrt{3}$ as before.

Problems Nos. 7 and 8.

See Fig. 5.



Problem No. 9.

A weight of P pounds lengthens the supporting spring to $l + e$ where $e = \frac{P}{\lambda} = \frac{mg}{\lambda}$. If the weight is set in vibration

$$m\frac{dy^2}{dt^2} = mg - \lambda y = -\lambda\left(y - \frac{mg}{\lambda}\right),$$

$$\text{let } y - \frac{mg}{\lambda} = x$$

$$\text{then } m\frac{dy^2}{dt^2} = -\lambda x, \text{ and } \left(\frac{dx}{dt}\right)^2 = -\frac{\lambda}{m}x^2 + c$$

$$\text{when } x = a, \frac{dx}{dt} = 0, \text{ hence } c = \frac{\lambda}{m}a^2 \text{ and}$$

$$\frac{dx}{dt} = \sqrt{\frac{\lambda}{m}(a^2 - x^2)}, \int_0^a \frac{dx}{\sqrt{a^2 - x^2}} = \sqrt{\frac{\lambda}{m}}\int_0^t dt, \text{ from which}$$

$$\sin^{-1}\frac{a}{a} = \frac{\pi}{2} = \sqrt{\frac{\lambda}{m}}\,t, \text{ therefore } t = \frac{\pi}{2}\sqrt{\frac{m}{\lambda}}$$

$$\text{The period is } T = 4t = 2\pi\sqrt{\frac{m}{\lambda}} = 2\pi\sqrt{\frac{e}{g}}$$

Problem No. 10.

Solution is similar to Problem No. 9 but for λ appears $\lambda + \mu$ and $T = 2\pi\sqrt{\frac{m}{\lambda+\mu}} = 2\pi\sqrt{\frac{e}{g}}$ where, as in the previous case e is the extension of the springs produced by the weight P.

Problem No. 11.

The rod is subjected to centrifugal forces in the plane of the axis and to accelerating forces in a plane perpendicular to the axis until the motor comes up to speed. Hence the rod is subject to greatest stress when both forces are acting and when both are greatest, this occurs just before uniform speed is reached.

The work done in accelerating the armature and rod from zero to n R. P. M. is $W = \frac{1}{2}\omega^2 (I_a + I\rho)$.

Since this is done uniformly in t seconds, the power expended is $P = \frac{1}{2}(I_a + I_\rho)\frac{4\pi^2 n^2}{3600} \times \frac{1}{550t}$.

The system is out of balance both statically and dynamically.

Problem No. 12.

Let x be the difference in ages, then when Mary was three times as old as Ann, Mary was $\frac{3}{2}x$ and Ann was $\frac{1}{2}x$. When Ann will be $3 \times \frac{3}{2}x$ she will be $\frac{9}{2}x$ years old. When Mary was $\frac{1}{2} \times \frac{9}{2}x$, Ann was $\frac{9}{2}x - x = \frac{5}{4}x$, then Mary is now $2 \times \frac{5}{4}x = \frac{10}{4}x$ and Ann is now $\frac{10}{4}x - x = \frac{6}{4}x$.

But $\frac{10}{4}x + \frac{6}{4}x = 44$, $4x = 44$, $x = 11$, hence Mary is $\frac{10}{4} \times 11 = 27\frac{1}{2}$ and Ann is $\frac{6}{4} \times 11 = 16\frac{1}{2}$.

When a space devoted to the proposition and solution of problems was suggested for the JOURNAL, it was hoped that such space might develop into a clearing house for the actual problems encountered in service ashore and afloat, research and original investigation. Research and original investigation, along engineering and Naval lines are of the utmost value, as pointed out by Commander C. S. McDowell, U. S. N., in the June number of the *Proceedings of the Naval Institute.* Practical, live, and up-to-the-minute problems can be furnished only by the members of the Society and the readers of the JOURNAL. *Come across!*

The following are not sufficiently serious to deserve a place in the JOURNAL but are given to furnish instruction and amusement to the studiously inclined.

Problem No. 13.

A ship A maintains speed and course. Another ship B, m miles abeam of A overtakes A by maintaining speed and changing course so as to always head for A. If A steams a knots and B steams b knots, how long does it take B to overtake A, how far does each travel and what is the course of B?

Problem No. 14.

If, as we carelessly put it, force times distance is work and force times lever arm is torque, how can it be explained that the dimension of both products is the same?

Problem No. 15.

A closed cylindrical vessel, filled with water, is made to revolve about its axis. In calculating the pressure at various points it is common to apply the expression for centrifugal force $\frac{mv^2}{r}$. Show that this is altogether wrong and work out the correct formula for two cases, (*a*) when the height of the cylinder is negligible and (*b*) when it is considerable.

Problem No. 16.

If a projectile weighs 125 pounds, how much would it weigh on the moon? How much difference would there be in the recoil in firing it?

Problem No. 17.

A heavy triangular boiler plate, sides *a*, *b*, and *c*, is lying on the floor. Which corner is the lightest to lift (opposite side resting on the floor) and which is the lightest to carry the plate by?

Problem No. 18.

A pile of coal is on deck, more is coming on board through a chute. Eleven men can clear the deck in twenty minutes, six men can clear it in sixty minutes, how long will it take four men?

NOTES.

BRITISH SUBMARINE BOAT BUILDING DURING THE WAR.

(Abridged.)

Messrs. Vickers' achievement in submarine construction during the war is one of which the firm has every reason to be proud. Fifty-four submarines of all classes have been built and commissioned in a period of fifty-one months of war, and are detailed as follows:

"E" class	15
"V" class	4
"G" class	6
"K" class	6
"N" class	1
"H" class	10
"L" class	9
Other types	3
Total	54

Of these boats, all except "V" and "N" classes were built to Admiralty design.

These figures are additionally interesting when it is remembered that in practically every class Messrs. Vickers were the pioneer builders. The outbreak of the war found the company in a remarkably good position for the rapid output of submarines. The type which was then being perfected, and of which several were in commission, was the now well-known "E" class.

This "E" class is one of the most numerous in the fleet. These vessels, as their performances have shown, proved themselves suitable for many types of work. Two of them, A.E. 1 and A.E. 2, after completion at Barrow, proceeded under their own power to Australia and took up duties with the Australian Navy. One of these vessels actually had considerably over 30,000 miles to her credit before it was necessary for her to undergo a refit to her propelling machinery. As sea-going boats they were a distinct step in advancement on previous classes. The extensive superstructure combined with the navigating bridge built over the conning tower made them easy to navigate in even the roughest weather. This advantage is the more appreciated when it is understood that only in the finest weather could a "B" or "C" class boat cruise on the surface with open hatches.

The overall length of the "E" class is 181 feet, beam 22 feet 7 inches over the side tanks, and the displacement when submerged is 780 tons. As regards armament, five 18-inch diameter torpedo tubes are carried, two in the bow, two on the broadside, and one in the stern. Each tube is provided with one spare torpedo, thus making a total of 10 torpedoes carried. The vessels have been fitted also with guns of various types, but a tabulated statement would be necessary to give full particulars of these.

The radius of action at a cruising speed of 10 knots is 3,225 nautical miles, with a total oil fuel capacity of 42 tons. A surface speed of 15 knots is obtained by twin screws which are each driven by a Vickers' eight-cylinder heavy oil engine of four-cycle, vertical, single-acting type, each engine developing 800 brake horsepower. The motors, for use when submerged, are of the Vickers' single-armature open type, each developing 420 brake horsepower, and resulting in a speed of 10 knots. The power for the motors is stored in two separate batteries of 112 cells each, constructed by the Chloride Electrical Storage Company, of Manchester. Air storage is provided by 57 bottles stowed about the ship. High-pressure air compressors keep the bottles charged.

To equip these boats for more effective scouting and patrol work, a wireless telegraphy installation is fitted, the aerial being carried on folding masts. In addition, a set of under-water signalling gear is carried. Two periscopes are fitted, one being a simple, single-power instrument, the other being fitted with a device which readily permits of alternative powers of 1 and 6 being used. The latter can also be used as a "sky-searcher" for detecting enemy aircraft.

Messrs. Vickers created a record as regards the building and equipment of the "E" class submarines, E. 19 being built, equipped and handed over to the British Admiralty in exactly eight months; whilst a flotilla of six, including the above, was commissioned in thirteen months from the date of verbal Admiralty instructions to proceed with their construction. During the period in which the company were engaged on "E" class construction, they were also devoting considerable attention to a new type of submarine in which the principal idea was the provision of a complete double hull.

The "G" class followed upon the Vickers' "B" design, to which reference will be made later. This is of increased size and armament. The "G" class (of which Messrs. Vickers constructed six) is 187 feet long, 22 feet 8 inches beam, with a submerged displacement of 840 tons. These dimensions follow the single-hull "E" class very closely, but with increased displacement consequent on the addition of the double hull. The full surface speed of these vessels is 15½ knots, obtained by twin Vickers' heavy oil engines, each developing 800 brake horsepower. The full speed submerged is 10 knots, the motors working at 420 brake horsepower each. The armament of the "G" class consists of two bow and two broadside torpedo tubes, 18-inch diameter, and one stern tube, 21-inch diameter, with a spare torpedo for each tube. The guns are two in number, situated on the superstructure at either end of the conning tower casing, one being of the disappearing type 3-inch Q.F., and the other 2-pounder H.A.

To augment the submarine fleet as quickly as possible, in the early months of the war, Messrs. Vickers placed the resources of their Canadian establishment at Montreal at the disposal of the British Admiralty. As a result of this arrangement 10 submarines of the "H" class were added to the service. These were designed by the Electric Boat Company, of America, and were sister vessels to some of the later submarines in the United States Navy. They formed a very handy type of small submarine, and did useful work in the Adriatic as well as in the North Sea. Their seaworthiness was fully proved during the voyage across the Atlantic. In December, 1916, the Admiralty placed an order with Messrs. Vickers for 12 boats of the "H" class, modified slightly from the American design to accommodate heavier torpedo equipment, and wireless telegraphy gear of a much higher power. Their length overall is 171 feet 9 inches, beam 15 feet 9 inches, and submerged displacement 510 tons. They have a speed of 13 knots on the surface, and 10 knots submerged. Twin screws are fitted, and the engines develop 480 brake horsepower. The electric motors have a total normal shaft horsepower of 640.

The chief feature in this class is the very powerful torpedo equipment in relation to their size. Four 21-inch torpedo tubes are arranged in the bows, and six torpedoes are carried. As in the case of previous classes Messrs. Vickers were entrusted with the first boat of the "H" class, the experience of their designing and constructive staffs making them eminently suited for pioneer work of this kind.

A class of "J" boats were built in the dockyards, and had each three sets of Diesel engines by Messrs. Vickers. These were the fastest heavy oil-engined vessels in the world.

The "L" class combines in design the best qualities of other boats, but with increased speed. These three vessels were delivered simultaneously—an incident which brought to the firm a special note of congratulation from the Admiralty.

The circular single hull is used with the side tanks as in the "E" boats, but the stern is a modified and improved arrangement of the stern fitted in another class. The length overall is 238 feet 6 inches, being 57 feet longer than the "E" class. The beam over the side tanks is 23 feet 6 inches, and the total submerged displacement is 1,090 tons. The Diesel machinery is of a more powerful type than previously fitted. The twin screws are worked by four-cycle, 12-cylinder oil engines and develop a total of 2,600 brake horsepower, which results in a surface speed of over 17 knots. Motors for submerged running are fitted to both shafts, and on a total brake horsepower of 1,600 a speed of 10½ knots can be maintained. The auxiliary machinery includes two high-pressure air compressors of the inverted water-cooled type, each capable of delivering per hour 22.5 cubic feet of air compressed to 2,500 pounds per square inch.

The torpedo equipment in this class consists of four 21-inch tubes in the bows, and two 18-inch tubes in the broadside room, with a spare torpedo for each of the tubes. A 4-inch gun is mounted on the superstructure just forward of the bridge and conning-tower. Very large angles of training are obtained by the use of a revolving platform which moves with the gun. A novel feature is the night periscope which is fitted in addition to the ordinary instruments. This enables the boat's crew to keep a more effective watch at night.

As the submarine requirements of the Allied Grand Fleet increased, it became necessary to have a type which, whilst still retaining the ordinary functions of the submarine, could yet maintain its station with the fleet when cruising. These requirements were embodied in the design of the "K" class, of which Messrs. Vickers were entrusted with the first ship of the type, and also five others. These vessels have a displacement when submerged of 2,570 tons, being 339 feet long overall, with a beam of 26 feet 8 inches. The double hull principle is embodied in a modified form, and the ends of the boat which might be damaged, without endangering the immediate safety of the boat have only a single hull at the sides. Their speed is 24 knots on the surface, the power being obtained from twin sets of geared steam turbines, which develop a shaft horsepower of 10,500. Steam is obtained from two boilers of the Yarrow type, with a working pressure of 235 pounds per square inch. The funnels are arranged to hinge down when preparing for diving; water-tight hatches cover the funnel openings as the funnels hinge back. The turbine machinery is supplemented by an 800 brake horsepower heavy oil engine of the Vickers submarine type, which is coupled up to a dynamo of the open single armature design. This arrangement enables the turbines to be reserved for higher speeds only, whilst the dynamo, in addition to charging batteries, supplies the main motors with power for cruising at economical speeds. For submerged work the motors develop a total horsepower of 700 per shaft, being arranged in tandem on each shaft, and give a speed of 9 knots. The motors

drive the shafts through helical gearing. The storage battery for the use of the motors is divided into three groups of 112 cells per group.

Owing to the very exacting duties required of these boats, additional protection for the navigating officer and quartermaster is provided in the form of a deckhouse built over and around the ordinary conning tower. The periscopes fitted into these boats were the longest which at that time had been made for the British Navy, having a length of 30 feet from eye-piece to head-piece. Another important accessory is the long-distance wireless telegraphy installation, enabling the commander of the submarine to keep in touch with his naval base when operating at great distances from it. The aerial is carried on telescopic masts, which can be raised and lowered at will. The air compressing machinery consists of two low-pressure and two high-pressure air compressors, with air bottles stowed in various positions about the vessel contiguous to their work. A telemotor system is installed for raising the periscopes and telescopic masts, and also for working the ballast tank vent valves.

The armament of this class includes four bow and four broadside tubes, all 18-inch diameter, with a spare torpedo for each tube. The guns are carried on the superstructure and consist of two 4-inch guns and one 3-inch gun for high-angle work.

These vessels are a departure from the ordinary type in that they are self-contained units of the fleet, and do not rely upon a parent ship as is the case of "E" and other classes. Their performances during the war have been of the greatest value to the naval authorities, their speed, armament and low visibility making them exceedingly useful additions to the British Navy. It is interesting to note that this class of submarine is, for surface work, the fastest in the world.

The "V" class was introduced at an earlier date as a result of tank experiments by Messrs. Vickers in which several forms of hull were tried. Four vessels of the "V" class were ordered by the Admiralty from the firm. The principal dimensions are length overall 147 feet 6 inches, beam of outer hull 16 feet 3 inches, and submerged displacement of 460 tons. Twin sets of Vickers heavy oil engines are fitted, developing 450 brake horsepower each, from which a surface speed of about 13 knots is obtained, the engines being of the four-cycle vertical single-acting type with eight cylinders. When submerged a normal full speed of 8½ knots is obtained from two motors each developing 190 brake horsepower. The storage battery consists of 132 cells arranged in two groups of 66 cells each. The torpedo equipment of these boats consists of two 18-inch diameter bow tubes and two spare torpedoes.

Minelaying submarines are a logical outcome of the war, and several of the "E" and "L" classes were equipped as such. The mines are loaded into vertical tubes which pass through the external tanks. Mechanical gear is fitted for both locking the mines in position and for releasing them when required.

The Vickers' engine being the standard for the British boats, the existence of spare-gear stocks all over the world prevents any radical departure in the design of the principal parts, but nevertheless, in developing the 8-cylinder reversing design, it was possible to make the main parts interchangeable with the 12-cylinder non-reversing type, and at the same time to make the weight less than that of the non-reversing engine of the same power and cylinder dimensions.

The construction of both engines is similar, so that in this respect one description suffices. The cast steel main bearing girders are connected longitudinally by forged beams. There are plate columns between the cylinder covers and the main bearing girders to relieve the cylinders of all vertical stress. (These engines are shown on folders in the next article.)

A cast-iron liner is dropped into a sandwich plate between the covers and columns, and is thus free to expand downward. A jacket of steel plate, corrugated for expansion, is fixed to the sandwich plate at the top, and is fitted with a sliding joint at the bottom between the jacket and the liner. Thrust reactions are taken by snugs butting against the bottom of the liner where it passes through the top plate of the crank-case. This top plate serves to tie the columns together.

The cylinder covers are of cast steel of simple construction, secured to the sandwich plate and to the columns. The joint is made by a cast-iron ring ground into grooves in the liner and in the cover. Water connections between the jacket and cover consist of tubes through the sandwich plate, passing into holes in the bottom of the cover, water-tightness being secured by soft packing rings around the tubes. No submarine engine cover has been known to fail in a Vickers' engine.

The valve boxes are separate from the cover, and are fitted upon coned seats in recesses in the cover. The valve boxes are water cooled by water from the cover. This water, in the case of the exhaust valve, passes into the jacket of the exhaust bend. The valves are of nickel steel, and the exhaust valve is water-cooled through flexible hoses. The piston is of cast-iron, with six upper rings and one wiper ring. They are non-water-cooled. An aluminum guard is fitted above the gudgeon to prevent oil splashing upon the crown. The connecting rod is hollow, of round section, with separate bottom end and compression liner. The crank is closed by portable sheet casings, and is ventilated by suction pipes to the induction header, non-return valves being fitted in the suction pipes to eliminate any possibility of a backfire into the crank-pit. The above-named features are common to both engines.

We come now to points of difference between the two engines. The 12-cylinder engine has the inlet and exhaust cams on a lower camshaft actuating the valves through push rods. The upper camshaft carries the fuel cams and drives the fuel injection pumps, one to each cylinder. This separate pump design is that originally preferred by the Service, but the spray valves have proved themselves such accurate means of regulating the fuel injected that a common fuel supply is now finding favor, and this is fitted in the reversing design. In this latter case the fuel is pumped into a common main from which are branches leading to the separate cylinders. No gags are required, as for air injection engines with a common fuel supply. This common supply pump is a four-throw pump driven by spirals from the end of the crankshaft. In the 12-cylinder engine the pump discharges may be connected at will, thus resulting in running on the "common rail" system as used in the eight-cylinder engine. The use of the common pump permits of one camshaft only in the reversing design. This shaft carries all cams, the air-starting cams being at the ends of the engine. The short push rods for the inlet and exhaust rods are pulled away from the cams by the rotation of a fulcrum shaft, after which the camshaft is slid longitudinally, and the push rods are then replaced upon the cams for running in the opposite direction. The fuel and air cams are bevelled, permitting the camshaft to slide without their tappets being lifted. All reversing is carried out by hand, it being desirable to avoid servo-motor gear, which generally gives trouble after some time at sea.

The 12-cylinder engine has the standard spray valve with external gland. The reversing engine has a flooded valve, in which the spindle does not project through a gland, but is actuated by a bell crank, the rotating shaft passing through a gland in the side of the valve-box. Both types give equally good results, and choice is made according to the ease of adaptation to the valve mechanism.

In each case the engine is started by air. The air is admitted in correct sequence by tappet valves with a spring and a balance piston upon them. By this means the valves are lifted off the cams when the air master valve is closed, and they only come into action when starting or reversing is required. The air passes to each cylinder through a non-return valve on the cover. The mechanical injection is so safe in its operation that there is no necessity to shut off air before admitting fuel. In the reversing engine it is arranged that the starting wheel shuts off air when all cylinders are on fuel, but in the non-reversing type the two are not interconnected. No cylinder relief valves are necessary for these engines, although in the reversing engines such are fitted to comply with the standard specification. The fact that the British submarine engine has no cylinder relief valves is practical evidence of the strength of the parts and of the safety of the injection system.

The control is different in the two engines. We may describe first that of the 12-cylinder engine. One hand wheel in the center controls the opening of all of the spray valves. Individual cylinders can be put in or out of action by the handles at each cylinder. A second hand wheel controls the output of the fuel pumps by sliding a shaft upon which stirrups moving the scroll cams actuating the suction valve of each pump are mounted. The horizontal wheel advances or retards the injection by moving vertically a coupling in the vertical shaft. This coupling is free to slide vertically on one part of the shaft, but drives the other through inclined keys. By this gear the upper camshaft can be rotated a few degrees relatively to the crankshaft. This gear is a refinement, enabling the spray cams to be set with great convenience to meet any conditions of fuel or load-speed ratio, which may vary considerably in a submarine charging when running on the surface, and it is not fitted to the reversing engine in which the duration of injection is so related to the first instant of injection throughout the range of control that automatic regulation sufficient for satisfactory running in all ordinary conditions is obtained. An emergency stopping valve is also fitted to the 12-cylinder engine, which releases the pressure from the rail.

The eight-cylinder engine control may now be described. The large hand wheel (Fig. 3 of next article) is for reversing, and a small hand wheel interlocked with the first wheel first admits air to all cylinders, then fuel to four cylinders, then fuel to the second four, and shuts off air. A further turn stops the engine by shutting off fuel. The pump output is controlled by a small lever regulating the closing point of the suction valves. The large upper lever controls the spray valve opening.

All cylinders in both engines are 14½ inches diameter by 15-inch stroke, and each easily develops 100 brake horsepower at 380 R.P.M. Powers up to 50 per cent in excess of this have been obtained at higher speeds, but a conservative rating has been followed by the Admiralty authorities. It is plain that high ratings must result in reduced durability, and the consistently steady running of the British submarines year in and out appears to point to the soundness of this policy.

The injection is of the Vickers' mechanical system, no injection-air compressor with its weight, space, complication and danger being required. Air compressors, however perfect the design, are considered the most troublesome parts of Diesel engines, and in high duty engines the supply and control of the high-pressure air is a serious problem. The system consists simply of a high-pressure pump supplying the fuel to a main, from which a definite amount is admitted each firing stroke by a measuring valve in the cylinder head, and passes to a simple spraying nozzle. The power is controlled by varying the duration of the opening of the spray valve, and at the same time adjusting the pump to the pressure required. Years of trial have been necessary to obtain the results now given, but in

its present development the injection is reduced to the simplest possible terms. The result is a system which can be run with little previous knowledge and with a minimum of attention or danger due to carelessness in adjusting. The consumption per brake horsepower is about 0.4 pound per hour, figures as low as 0.381 at full power on official trials independently recorded being obtained, even in war-time hurry of delivery.

One or two points in the design may be noted. The first is the extreme accessibility gained by the plate column construction. This renders it possible for engines to be maintained and refitted by ship or depot staffs without calling in dockyard or manufacturers' assistance. The second is the conservative rating and stresses. Thereby extreme durability is obtained and serious breakdowns are avoided. The weight per brake horsepower of an engine should always be considered in connection with the rating and stresses allowed. The Vickers' construction is in principle a very light one, and even with the low rating results in a weight per brake horsepower of 58 pounds for the bare engine, calling the power 1,200 for the 12-cylinder engine. This weight is reduced to below 50 pounds if the power be taken as 1,400 horsepower, which is easily obtained, and would be very materially decreased if the piston speed were increased to the high figure of 1,323 feet per minute, as is obtained in some of the German "U" boat engines. The third notable feature is the avoidance of special methods of manufacture. While the best material and workmanship are used, special steels are avoided, as also are heat treatment of details and parts requiring very special tools or processes of manufacture. Thus spur wheels are used wherever possible in preference to spirals. The engine thus becomes an ordinary manufacturing and refitting proposition, and no danger arises if a broken part is replaced in ordinary material. Such a policy permits boats to be sent to foreign stations with more assurance than if they were dependent for upkeep upon expert supervision during repair.

Finally, are simplicity and safety. All adjustments are obvious and readily carried out, and the abolition of the air compressor renders the engine particularly simple to understand and to run.

The main propelling machinery of the "K" boats consists of two sets of single reduction geared steam turbines and two boilers of the straight-tube three-drum type, having a working pressure of 235 pounds per square inch and arranged for burning oil fuel. Each set of turbines consists of one high-pressure and one low-pressure cylinder, both turbines driving the main line of shafting by double helical gearing. An astern turbine is incorporated in each low-pressure turbine. The full power ahead shaft speed is 400 R.P.M., the corresponding turbine speeds being, high pressure 3,500 and low pressure 2,800. The main motors, which are in the wings of the ship, somewhat above the shaft centers, are also connected to the propeller shafting by double helical gearing, the ratio in this case being 2 to 1. The turbines can be declutched from the line of shafting when desired, while clutches are also fitted between the main motors and the shaft line. This latter set of clutches must be disengaged when the main shaft is running at above 220 R.P.M., and this uncluteching is carried out by hand or automatically by governor gear. The turbines are installed in a separate compartment, water-tight bulkheads being provided at the forward and after end of the compartment, with two doors in the former, one for access to the boiler room and the other to the main passage way to the forward part of the vessel; and one door in the aft bulkhead leading to the motor room.

The boiler room contains, in addition to the boilers, the feed pumps, oil-fuel pumps, heaters and filters, and forced-draught fans, the latter being driven by impulse steam turbines. A hinged funnel is provided for each boiler, arranged so that it may be lowered into the superstructure and the

opening closed by a strong steel cover, both operations being performed simultaneously by means of an electric motor placed in and operated from the turbine room. In later boats a hydraulic semi-rotary engine is used. As a precaution against accident in the event of the funnel covers being damaged, an additional valve of special design is fitted on the hull of the vessel at the base of the funnel uptake. The covers for making watertight the air vents in the boiler rooms are hydraulically operated from the boiler room. In later boats of the class these covers are in duplicate. Arrangements are provided for shutting off the supply of oil fuel to the boilers before the funnel opening can be closed. The turbines, boilers and all hot surfaces are carefully and thoroughly lagged with incombustible, non-conducting material, with the object of reducing the temperatures in the engine room and boiler room to a minimum, and an efficient system of ventilation is provided throughout the machinery compartments.

For cruising, it is possible to use an eight-cylinder 800 brake horsepower oil engine of the submarine type. This engine drives a dynamo which can be used for charging the batteries and for driving the ship at cruising speed by electrical transmission to the main motors. The auxiliaries for the oil engines are on the same lines as those fitted in ordinary submarine practice.

The auxiliary machinery in the ship is of the usual pattern for submarine service, though somewhat larger in cases. Two compressors are fitted for charging the 2,500 pounds high-pressure air bottles, of which over 100 are fitted in the vessel. One of these compressors is motor driven and the other is direct driven from the end of the generator shaft. Two low-pressure air compressors are fitted for supplying air for blowing the water from the main ballast tanks when the vessel has broken surface. Two three-throw double-acting reciprocating bilge pumps, driven by electric motors, are also fitted for pumping the tanks and bilges. The telegraphs are of the ordinary mechanical type fitted with electric bell replies.

A special feature of these boats is the fitting of hydraulic power for various operations, such as working vent valves in the ballast tanks, air intakes in the boiler room, and the raising and lowering of the periscope rams and wireless masts. In the later boats this system is also applied to the funnel covers. The steering gear, and also the forward and after hydroplane diving gears, are operated by means of motor-driven Variable-Speed Gear Company's hydro-electric units, one for each service, controlled from pedestals placed in the control room. Hand gear is fitted in each case for emergency use. The steering gear itself is of the usual submarine screw-gear type.

The forward hydroplanes are of the housing type, the planes sliding inboard along the shaft into the superstructure to protect them from heavy seas and during high-speed running on the surface. This operation is effected by hydraulic power, but hand emergency gear is also fitted.

The torpedo equipment of these vessels consists of four 18-inch torpedo tubes in the bow and four 18-inch broadside tubes. In later boats of the class the bow armament equipment consists of six 21-inch torpedo tubes.

This history of submarine boat and engine design and construction when carefully examined shows that the underlying principle has always been the carrying of weapons of offence. The torpedo is the weapon which has naturally developed as the submarine's particular equipment on account of the ease of firing when the boat is either submerged or awash. But guns of increasing caliber are being adopted.—"Engineering."

HEAVY OIL ENGINES FOR BRITISH SUBMARINE BOATS.

The 12-cylinder engine is one that has been made in large numbers during the war by Messrs. Vickers, both at their works at Barrow-in-Furness and at Ipswich. It has also been manufactured by a number of firms working under license from Messrs. Vickers. The latter firm has latterly introduced various improvements in detail and in arrangement of controls, and as these, owing to the necessity of rapid production, were not wholly incorporated in the engines made by licensed firms, who were working to Admiralty instructions, the description we now append will include points interesting even to those who are fully conversant with the earlier engines. This 12-cylinder engine is shown in elevation in Fig. 1, while a cross-section is given in Fig. 2.

The peculiar framing construction of the engines is plainly evidenced by these drawings. First of all, it will be noticed that each main bearing is carried by a separate steel casting, and these castings are recessed into longitudinal beams, athwartship fitted bolts, not shown in the drawings, tying the two together. This construction obviously entails considerable care in chocking the engines in the boat, but with trained workmen no difficulty arises, and the required accuracy is obtained in a surprisingly short time. In adaptations of these engines when weight was relatively unimportant, a cast bedplate has been substituted, and a similar design carried out in steel is, with modern foundry methods, applicable to the light weight engines, and would probably be proposed for future work where interchangeability with previous parts, as for Admiralty work, is not important. In this respect, as in many other points in the engine, some of which will be subsequently mentioned, the designers have been handicapped by their own success, as improvements which experience has pointed out to the firm were sometimes not acceptable on account of the necessity of maintaining uniformity with the large number of engines already in commission.

The columns consist of boiler plate somewhat less than thirteen-sixteenths inch in thickness. At the top is a forged steel head into which the column plate is rabetted, three rows of rivets securing the head to the column plate. The plate is cut with lightening holes, and at the bottom is branched by a slot cut for removal of the main bearing cup. To the lower extremities of these branches are riveted four forgings, forming the feet. These are of approximately triangular elevation, and are plainly visible in the sectional view. The riveting of the heads and feet of the column is most carefully carried out, the holes being reamered and the rivets inserted alternately from opposite sides to avoid bending the column. The column is stiffened by light angles on its outer edges, these angles forming the facing for light sheet steel plates forming the sides of the crank-case. Small circular hand doors are fitted in the outboard casings to facilitate feeling the liner and lower bearings. Further stiffness is given by angles plainly shown on the elevation which support the horizontal tie-plate below them. This tie-plate has a hole in it slightly larger than the cylinder jacket bottom flange, and supports the latter by means of four adjustable snugs bolted to the tie-plate. On the column head is placed a sandwich or distance-piece, which takes the weight of the liner, and to which the cover is secured by six 1½-inch studs. The connecting joint consists of a cast-iron ring ground into both liner and cover. The main impulse load is transmitted from the covers to the columns by two studs and four bolts, 1⅝-inch diameter, for each column between adjacent cylinders, two bolts only in addition to the studs being fitted to the end columns of each of the four groups of three cylinders, into which it will be noted the engine is divided.

This framing construction permits of close determination of stresses and lends itself to a light-weight engine, but the main practical advantage is in the extreme accessibility it gives to the crankhead and main bearings, while a cylinder is rapidly replaced should occasion arise. Accessibility and facility of overhaul are, of course, of the utmost importance for marine work.

The cover, it will be seen, is a simple steel casting, the inlet and exhaust valve boxes being separate from it. These boxes seat upon coned joints in the cover, a ground metal to metal joint preventing leakage from the compression space. They are very thoroughly water-cooled, as will be seen in the elevation, the inlet valve-box even having a recess turned on its exterior into which water from the cover has access.

The water joints between the top of the cover and the valve boxes are made by indiarubber rings compressed below the flange of the latter. While no trouble is experienced on service, yet in later engines Messrs. Vickers make this joint by a pair of rubber rings in grooves on the periphery of the box, which enter into a slight recess in the cover. The advantage of this is that the joint becomes a sliding one, automatically compensating for any wear due to grinding down of the valve-box. A similar water joint is fitted between the bottom of the liner and the jacket, the two grooves being visible in the illustrations.

The exhaust and induction valves are of nickel steel, the former being water-cooled by flexible indiarubber armored hose connected to the valve head. The inlet water passes down a central tube to the bottom of the exhaust valve and escapes upwards around this tube. The practice of water-cooled exhaust valves is followed by Messrs. Vickers even in their smallest submarine engines, one advantage being that the spindle clearances may be kept fine so that on starting the leakage of gas into the boat will be negligible compared with that from uncooled valve spindles in which a comparatively large clearance has to be allowed for expansion due to heat.

The separate valve-spindle guides will be seen in the section in Fig. 2, taken at the No. 11 cylinder, this being in accordance with the desire for extreme durability of all parts. Lubrication is not now fitted to the valve spindles. The head gear calls for no particular comment beyond stating that the spring spindle has a tee-end at its lower extremity, so that if it is depressed and then turned through a right angle about its axis it can be readily removed with its spring.

The cylinder proper is very elementary in form, and consists of a plain cast-iron liner surrounded by a corrugated sheet steel jacket. This latter terminates at its lower end in a pressing forging, to which it is welded, and at the top a flange is welded to the jacket and is jointed to the underside of the sandwich plate. The liner has a number of steel bosses riveted through it, as indicated in the elevation of the eight-cylinder engine (Fig. 3). These bosses are machined to form stuffing boxes through which the piston lubrication connections pass; these connections being screwed into the liner. Eight of these feeds are fitted to each cylinder, and are supplied by a sight-feed force lubricating pump. In practice this pump is set to a low output, as very little lubrication is required for the piston.

The piston is of simple design in cast-iron. The top is concave and fitted at the center with a screwed hole for a lifting bolt. This hole at one time held a special plug designed to maintain a high temperature, and thus to facilitate combustion, but this was found unnecessary and is not now fitted. Though the hole is left open to the flame, no harm is occasioned thereby, the main impact of the injection not coming upon the center of the piston as in an air-injection engine. There are six piston rings, 0.375 inch wide at the upper part of the piston, and one wiper ring at the bottom.

The gudgeon pin is pressed hollow from special case-hardened steel, a plug being subsequently fitted to exclude the oil. The diameter is in three steps, as is usual, and is tightly driven into the pisotn, being secured at one end by a set pin and at the other by a key. A light aluminum guard is fitted over the top of the connecting rod and is secured by the gudgeon-pin set screw and by a special stud at the opposite side. The somewhat complicated lower guard originally fitted has been abandoned.

The connecting rod is of plain turned design. The top end is spherical with a non-adjustable gudgeon bearing, consisting of a bronze bush pressed into the eye of the rod and lined with white metal. This bush has a radial hole through it at the middle of its length, this hole communicating with a groove turned in the eye of the rod. By this means, if the bush should by accident or carelessness turn slightly, the oil supply from the hollow rod is not interrupted. The lower end of the rod is forged into a palm in which the crankhead brass is spigoted, provision being made for a compression plate. The crankhead brasses are of bronze, white-metal lined, with a circumferential non-staggered oil groove at their middle length. The lubrication oil passes into the top of the main bearings, thence through the crankshaft to the crank-pin, from thence up the rod to the top end. It will be noticed that this design of crankhead is somewhat heavy, and Messrs. Vickers have adopted a modified design in cast steel for crankheads of their non-Admiralty work.

The crankshaft in the 12-cylinder engine is in four three-throw sections, and was maintained at the same diameter as the solid shaft in standard six, eight and ten-cylinder engines, namely 7½-inch. Nickel-chrome with hollow journals and pins was originally fitted throughout the large engine, mainly to save weight and to gain experience of this material in such shafts, the maximum stress not being materially affected by the addition of the extra cylinders. Difficulties in supply during the war led to this being, in a number of 12-cylinder engines, used only for the aft two lengths, the solid carbon steel pattern as originally used in the smaller engines being used for the forward lengths. All these shafts are oil-toughened, and the pins are trued by hand and lapped after turning.

The exhaust main is not shown on the drawing, but it consists of a pair of water-jacketed headers, one for each six cylinders, built up in lengths with independent outlets to atmosphere. The Admiralty engines are fitted with cast-iron mains, but for ordinary purposes welded sheet steel has proved quite satisfactory. The order of firing of cylinders is 1, 7, 3, 9, 2, 8, 6, 12, 4, 10, 5, 11, and deflecting diaphragms are fitted in the mains to prevent interference between the cylinder exhausts.

The flywheel is of cast-iron fitted with teeth on the outside to engage with a three horsepower electric or hand-turning gear of Vickers' patent, specially designed for instant operation, and to meet the limited space available. The center eye of the wheel is separate from the rim to which it is bolted by a series of bolts shown in Fig. 3, and it is divided along its diameter to facilitate machinery overhaul in the boat.

The 12-cylinder engine illustrated is of the latest class, in which the unit system of fuel pumps originally favored by the submarine service is fitted. In this the inlet and exhaust valve cams are fitted on a shaft running in ring-oiled bearings, at about the middle height of the engine. The lower end of each of the long push rods carries the case-hardened steel roller, and on either side of it is a guide block sliding upon specially prepared guides in the cam casing. A loosely fitted cover surrounds the push rod, and excludes dirt from the casing. A lead from the bearing oil supply is led to each cam roller and guide, the oil entering at the back and squirting into the hollow interior of the roller block, as shown in Fig. 2. The cam casings drain back to the crank-case, the only oil remaining in them being

that in the small troughs under each cam into which the latter dip. The cams are wide, and are made of case-hardened steel pressed to a hollow section. The cam-cases—which were originally of aluminum alloy, but owing to other demands for that material have during recent years been made in cast iron—are bolted to the camshaft brackets, and are provided with a footstep to facilitate access to the top gear. The lower camshaft is driven by spur gearing in the middle bay of the engine, while the upper camshaft receives its motion through a bevel-driven vertical shaft visible in the middle of Fig. 1. The timing gear on the vertical shaft is also shown on this illustration. On rotating the horizontal wheel it is moved vertically upon the thread shown, and thereby advances or retards the upper shaft relative to the crankshaft owing to the upper bevel wheel being driven through a number of spiral keys on a coupling moved vertically by the hand wheel and sliding on straight keys on the vertical shaft. As the upper shaft carries the fuel admission cams, this effect is analogous to that of moving the "spark" in a petrol engine. It is a refinement not usually applied to Diesel engines, but intelligently used it enables the best setting for any condition of working to be obtained.

For ordinary running the spray valve, when at full power, is due to be opened at about 16 degrees, measured on the crankshaft, before the top dead center of its piston, and the controls, which will be presently described, have been re-designed so that as the duration of the spray valve opening is reduced for lower powers; the point of injection is simultaneously adjusted to that suitable for ordinary surface conditions. With these conditions it is unnecessary to adjust the timing gear when varying the power, but in the event of a heavy "charge" being put upon the main motors of the boat, thus considerably increasing the load on the engine, it is possible to retard the injection a few degrees or with a light condition of the boat or a following wind the timing may be advanced slightly. Adjustments of fuel valve settings to suit variations of fuel are also very conveniently carried out in similar manner.

Messrs. Vickers have carried out extensive trials in various conditions to investigate the effect of the timing gear and the result is to show that within the limits of practical working the brake horsepower and maximum cylinder pressure are both increased by advancing the injection, the curve of increase on a base representing the angle of injection being a straight line. Indicator cards varying in character from the flat-topped card representative of the normal air injection engine to the sharply-peaked card of the explosion engine, can be obtained at will, and the whole forms a most interesting study. In ordinary trials the firm limits the maximum pressure to a more reasonable figure, but on occasions on service where extra speed has been required the engines have been run with timing gear adjusted to give cylinder pressures of 700 pounds per square inch and over without any ill-effect. The control of the spray valves is effected by the left-hand vertical hand wheel seen in Fig. 1. This, by gearing, partially rotates the spray valve control shaft, the lowest of the three shafts running along the top of the engine. At each cylinder this shaft has a notched lever keyed to it. Alongside this lever is a similar lever with a spring clutch handle, the second lever being fixed to a short sleeve riding on the spray valve control shaft. When this sleeve is rotated by the handle the eccentric fulcrum mounting of the spray valve lever is partially turned by means of the two levers and the connecting rod, plainly seen in Fig. 2. The eccentricity of this mounting and the link proportions are so designed that a close approximation to the required point of fuel admission to suit any reduced duration of admission is obtained. Ordinarily the clutch handles are pushed forward to engage with the levers on the control shaft, in which case all spray

valves are controlled by the hand wheel, and over a wide range of power a movement of this wheel is all that is required to regulate the power. Should it be desired to cut out any cylinder the handle is drawn down, disengaging the sleeve lever from the one alongside it, and on bringing the handle forward to a notch in the fixed quadrant, as shown dotted in Fig. 2, the spray valve is put out of operation, a small cam on the sleeve lifting the suction valve of the fuel pump and putting it also out of action as the spray valve ceases to operate.

The whole is particularly simple, though the repetition of the units for each cylinder gives a first impression of complication, but it is plain that experience was necessary to enable the required somewhat complicated co-relation of functions of timing and duration to be obtained by such an elementary form of apparatus.

The fuel pumps at each cylinder are eccentric operated and consist of bronze castings supported in a steel casting secured to the cylinder cover. This casting carries the upper camshaft bearing, on the cap of which is mounted a separate small bearing in which the top-most shaft slides. This shaft is actuated by the right-hand wheel in the center of the engine, and by means of a downwardly-projecting stirrup slides a spiral scroll cam at each pump to the position required for the correct fuel output. This output is varied as the cam does not allow the suction valve of the pump to close till the desired point in the downward stroke of the latter. The high-pressure pump is marked on No. 12 cylinder in Fig. 1, and the spring returning the tappet for the suction valve can be detected in the drawing. The bore of the pump is ⅛ inch and its stroke 1 inch, special soft packing being used in the gland. Ordinary webbed cone-seated valves are usually fitted, but ball valves have been found equally efficient, and are now finding favor in the service. The whole of the bracket, pump and details have been redesigned in Vickers' later models with advantages as regards ease of manufacture, weight and efficiency, but in so doing, interchangeability has been maintained to a considerable degree of detail.

The fuel from the pump passes through the pipe shown on the right of it to a strainer, and thence into an accumulator tube shown vertically just to the left of the right-hand column on No. 12 cylinder. It then passes to the spray valve. The strainer at one time consisted of a plate with fine holes drilled in it, but the later type, which is much cheaper and affords greater filtering area, consists of a series of perforated discs, each with a shallow circular projection on one face close to the edge. This projecting annulus is knurled, and a number of these discs strung on a central bolt form a cartridge with circumferential rows of tiny triangular holes on its surface, through which the fuel passes to the center and thence through the end plate to the outlet pipe. A vent valve is fitted to the spray valve body, this valve, for convenience, being fitted on the head of the pulsator, which casting also forms the strainer body. The pulsator is a slightly flattened steel tube, and its function is to receive the fuel charge from the pump, when this is supplying only its own cylinder, pending the opening of the spray valve. A pressure gage is mounted on the discharge pipe so that the pumping plant for each cylinder is complete in itself, as originally specified. At the bottom of the pulsator a valve is now fitted, and through this valve each pulsator can be connected to a main, originally fitted for priming purposes. The common practice is now to run with the pulsators coupled to this main, in which case the pumps are, of course, not measuring the fuel to each cylinder, the spray valves performing this function. This is opposed to the ordinary idea, but consideration will show that the valve is more likely to be accurate than the pump. The system thus run becomes a pressure

system, and all that is necessary is to maintain the required pressure and to adjust the spray valve functions to regulate the power. A development of this system will be seen when the eight-cylinder reversing engine in Fig. 3 is described.

A safety valve is fitted to the pressure rail in the center of the engine, as is also a quick opening valve for immediately stopping the engine in case of emergency by releasing the fuel pressure.

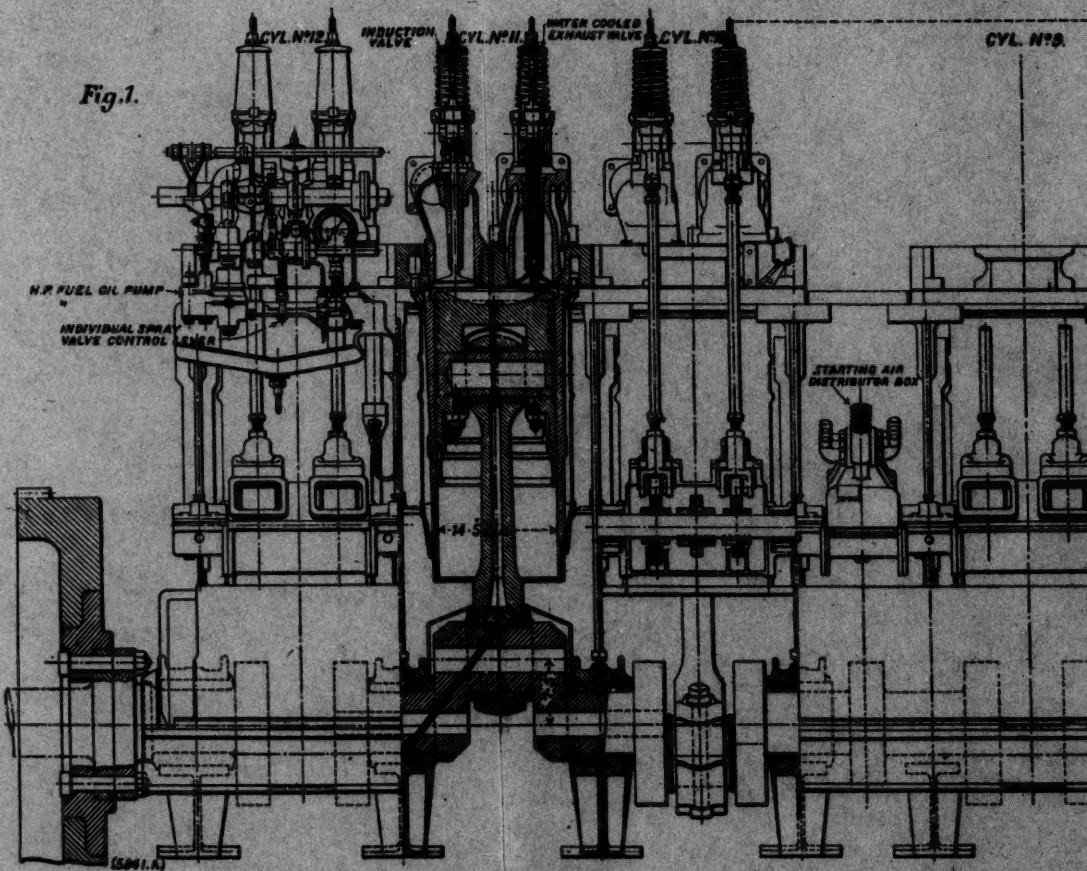
The spray valve in the standard engine is an ordinary spring-loaded conical valve, made in hard steel. The gland is packed with fuel-pump packing and, with reasonable care in first packing, is perfectly satisfactory. The valves can be individually adjusted by the nuts seen on the end of the spindle. The nozzle is of tool steel and its securing nut is bedded upon the coned seat in the cylinder cover so that there is no tendency for fuel to leak through joints to the cylinder. The number and disposition of the holes in the nozzle depend upon circumstances, but in the engine described they are five in number, and 0.0205 inch in diameter, the jets being at 68 degrees with the axis of the cylinder.

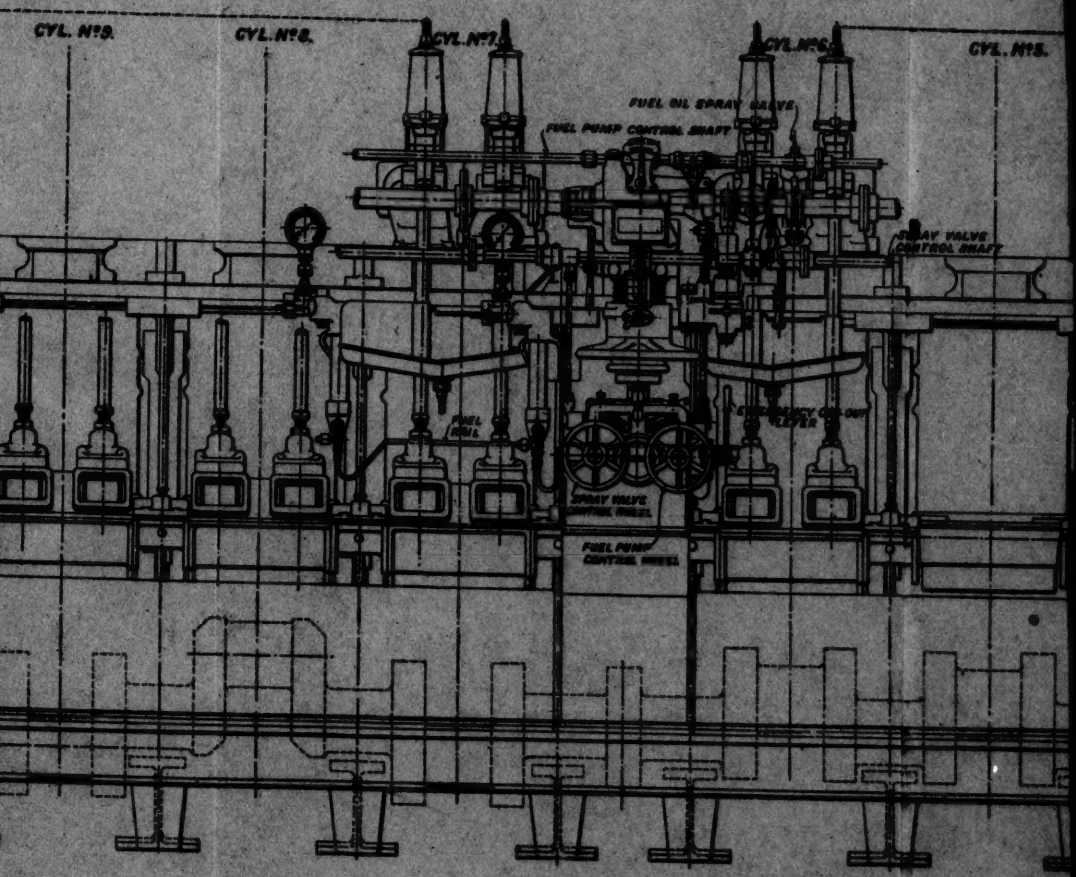
The lower part of the spray valve-box is a steel stamping, the upper part, which contains the spring and the guide plunger upon which it bears, is of cast steel, the eccentrically-bored fulcrum bearing of the spray-valve lever being mounted between the two parts. The spray valve is operated by a lever of the first order, shown in Fig. 2, which has a wide roller loosely mounted in a groove at its inboard end, this roller engaging with the fuel cam. The fuel cam consists of a small hardened toe-piece mounted in a steel cam disc on the upper camshaft and at the center line of the cylinder, and is capable of slight circumferential adjustment on its disc. A sheet save-all is fitted under each pump, and by means of a drain pipe avoids waste of fuel when cleaning filters or venting the system.

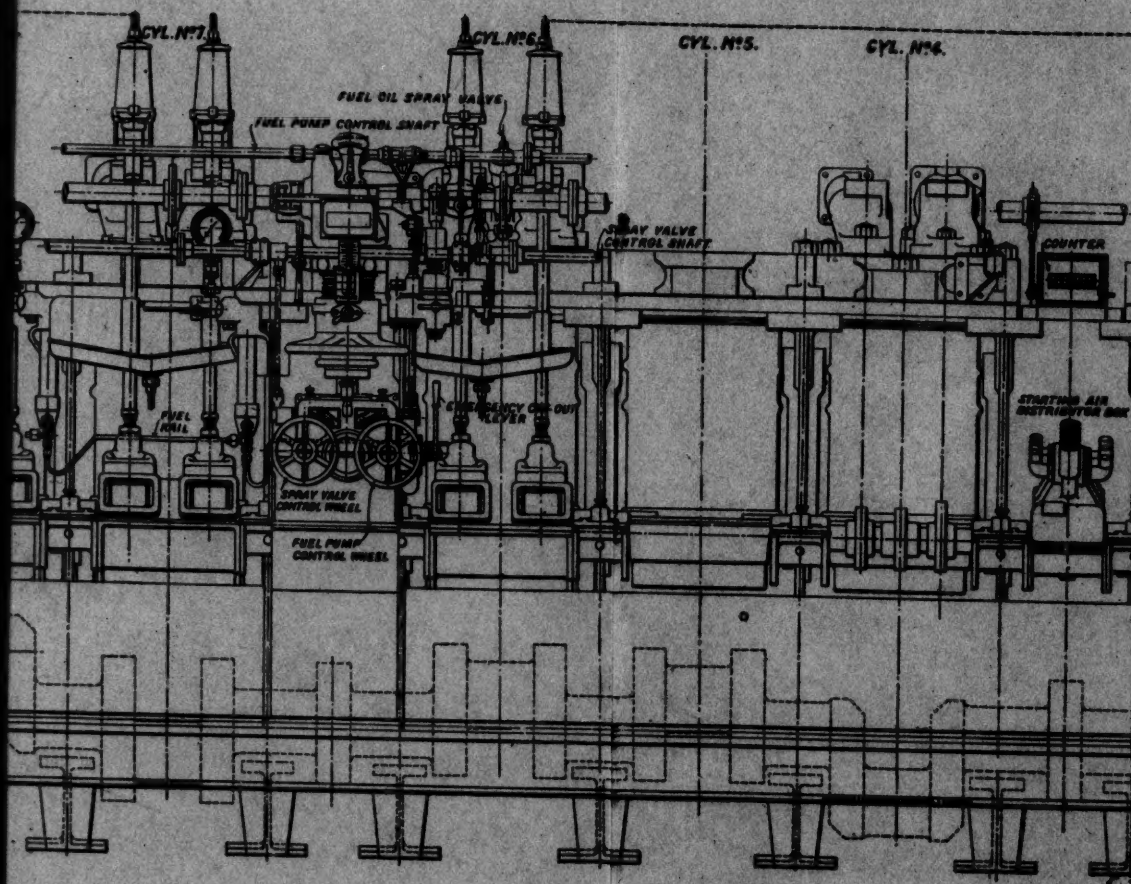
The engine is started by opening a T-handled air master valve, situated near the center of the engine, which admits air to the two starting air boxes between the end groups of cylinders. In these boxes are small partially-balanced valves, normally kept off their seats, and thereby free of the cams, by a light spring. When air is admitted the valves are blown down upon their seats and are operated in correct sequence by cams on a pair of athwartship shafts bevel driven from the lower camshafts. At one time air starting was regarded as an emergency measure, the electric motor being ordinarily used in submarines. Air starting valves fitted with hardened ends engaging with the cams were satisfactory in such circumstances. Nowadays air starting is recognized as safer in the event of water having entered the engine during driving, and the air-starting valves have been provided with hardened steel rollers to give increased durability, a very neat little design having been adopted. The air passes from the air-starting box to the individual cylinders, passing into the cylinders through a spring-loaded non-return valve on the cover. As seen in Fig. 2, it passes through small holes after leaving the non-return valve so that no broken part can enter the cylinder in case of breakage of a valve. The engine having started on air the spray valves are put in gear, and afterwards, when convenient, the air master valve is closed. With pipes and pumps fully primed, firing begins within the first two or three revolutions, the absence of the chilling effect of the injection air doubtless accounting for the ease in starting.

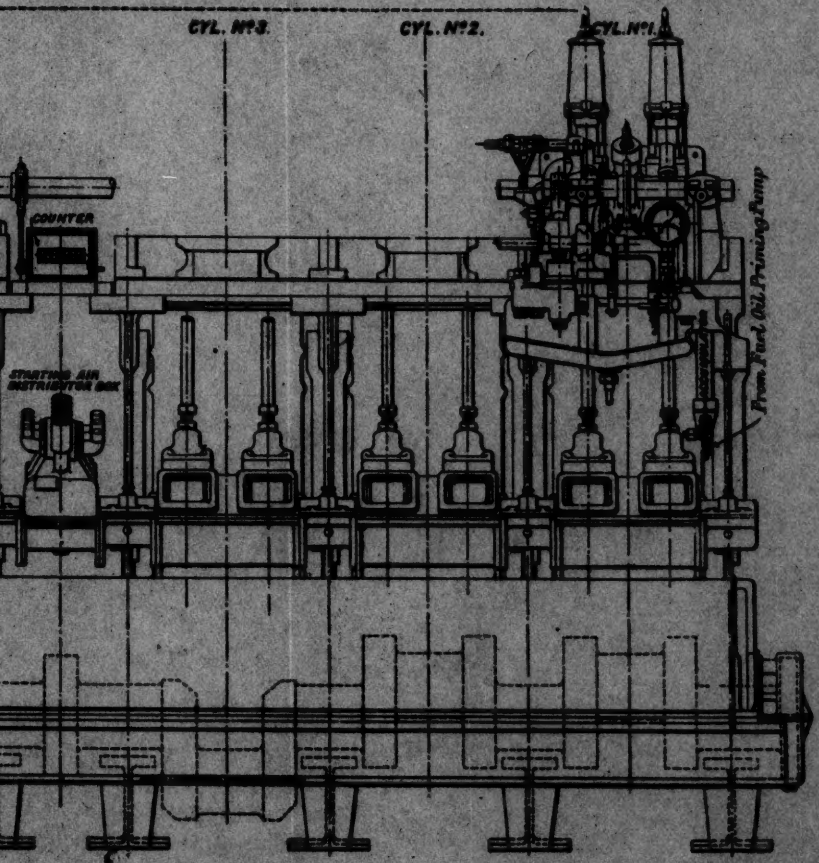
At the back of the engine is a bearing oil pump, of double-acting type, and a plunger pump for maintaining the gravity fuel tank full. These pumps run at half engine speed, and are driven by bevels from one of the starting air camshafts. In some boats where automatic compensation of fuel by sea water pressure is fitted, the gravity fuel pump is discon-

Fig.1.


CYL. N°12
INDUCTION VALVE
CYL. N°11
WATER COOLED EXHAUST VALVE
CYL. N°10
CYL. N°9
H.P. FUEL OIL PUMP
INDIVIDUAL SPRAY VALVE CONTROL LEVER
STARTING AIR DISTRIBUTOR BOX
14.5
(S.W.I.A.)


CYL. N°9.
CYL. N°8.
CYL. N°7.
CYL. N°6.
CYL. N°5.
FUEL OIL SPRAY VALVE
FUEL PUMP CONTROL SHAFT
SPRAY VALVE CONTROL SHAFT
FUEL OIL
SPRAY VALVE CONTROL WHEEL
FUEL PUMP CONTROL WHEEL


CYL. N°7.
CYL. N°6.
CYL. N°5.
CYL. N°4.
FUEL OIL SPRAY VALVE
FUEL PUMP CONTROL SHAFT
SPRAY VALVE CONTROL SHAFT
COUNTER
FUEL RAIL
SPRAY VALVE CONTROL WHEEL
FUEL PUMP CONTROL WHEEL


CYL. N°3.
CYL. N°2.
CYL. N°1.
COUNTER
STARTING AIR DISTRIBUTOR BOX
From Fuel Oil Priming Pump

SECTION THRO' N°II CYL.R

Fig. 2.

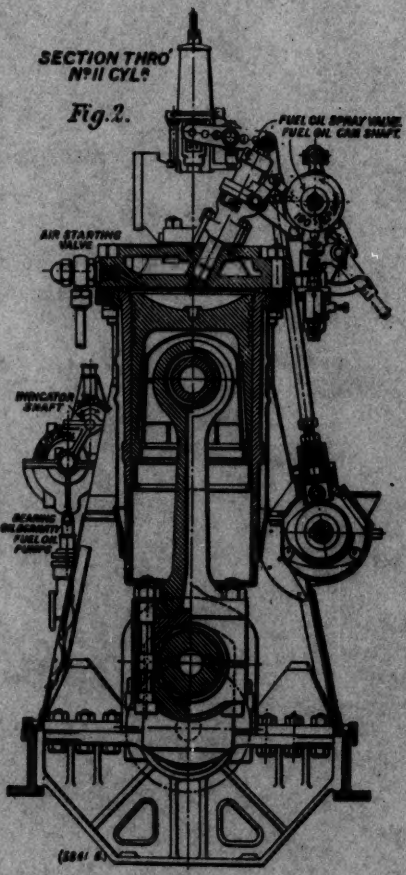
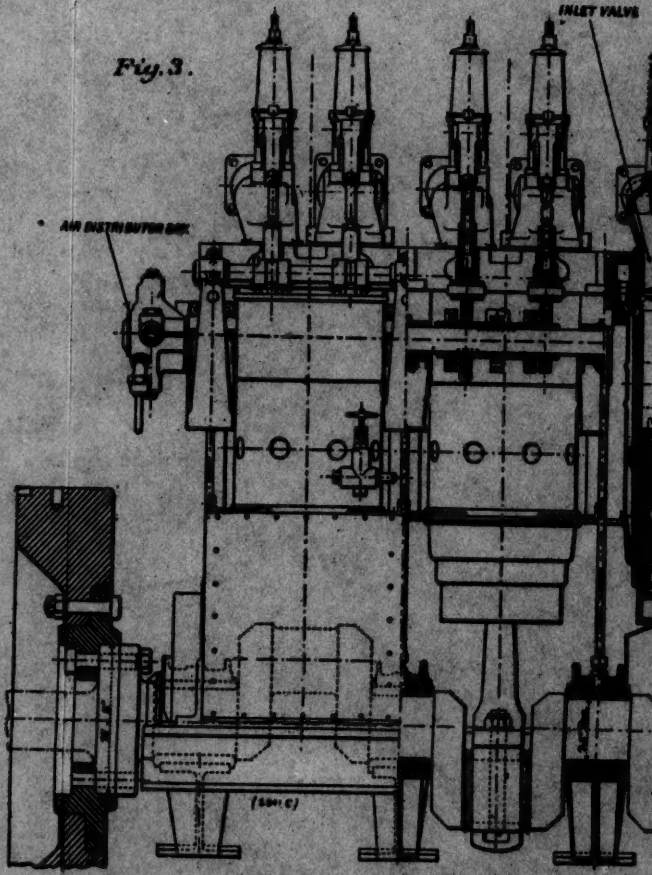
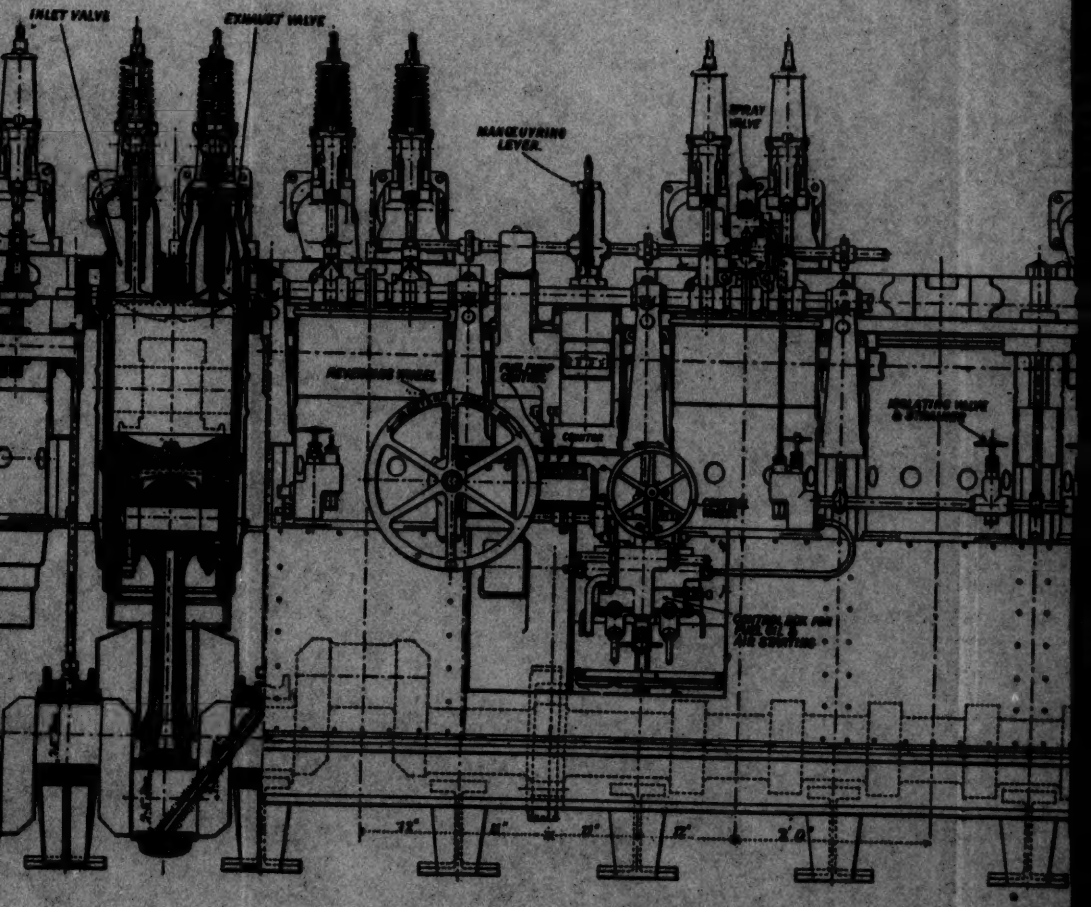


Fig. 3.




INLET VALVE
EXHAUST VALVE
MANOEUVRING LEVER
SPRAY VALVE
REVERSING WHEEL
ISOLATING VALVE
CONTROL VALVE FOR AIR CLEANER
3'6"
3'6"
3'6"
3'6"
3'0"

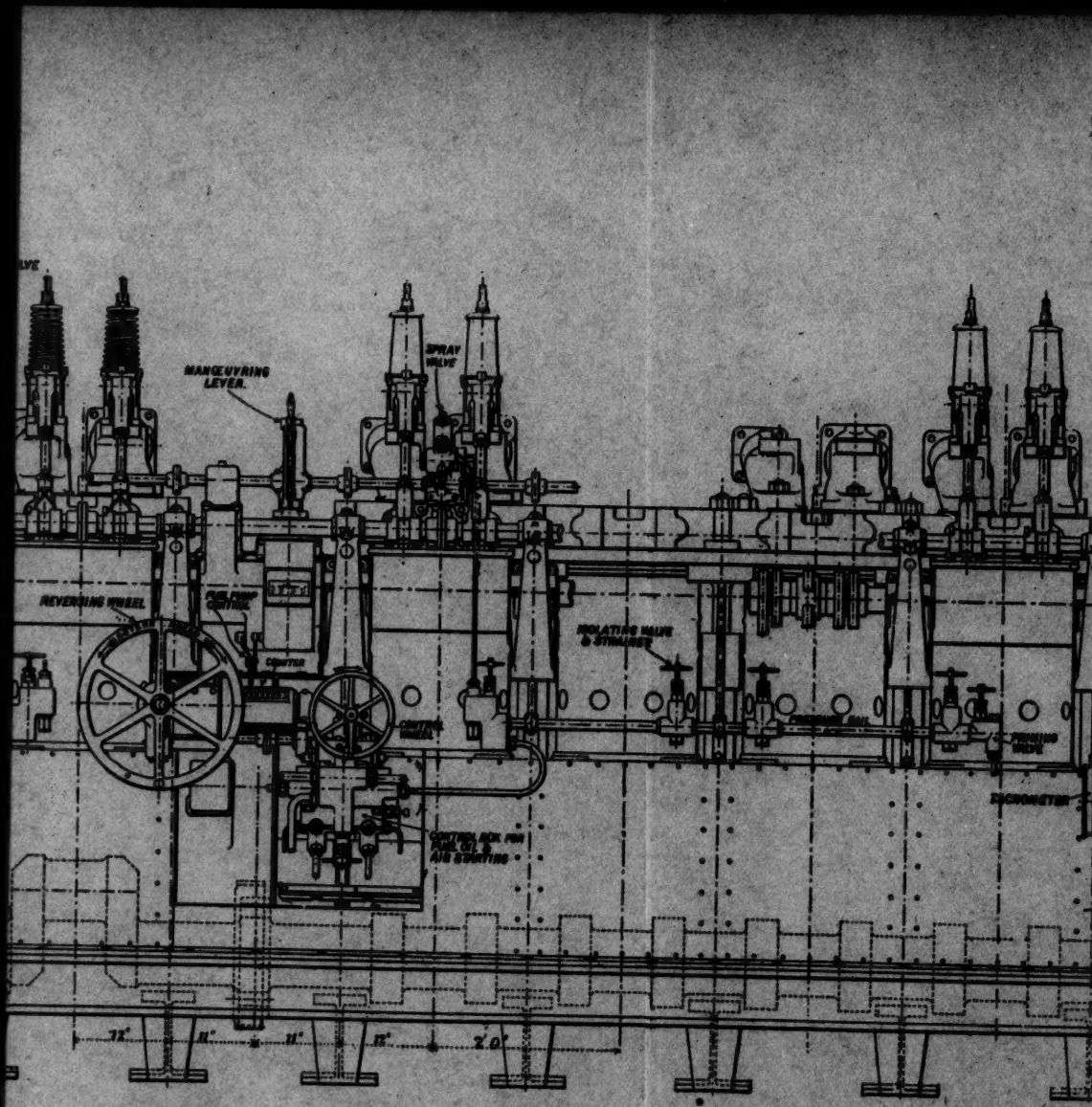
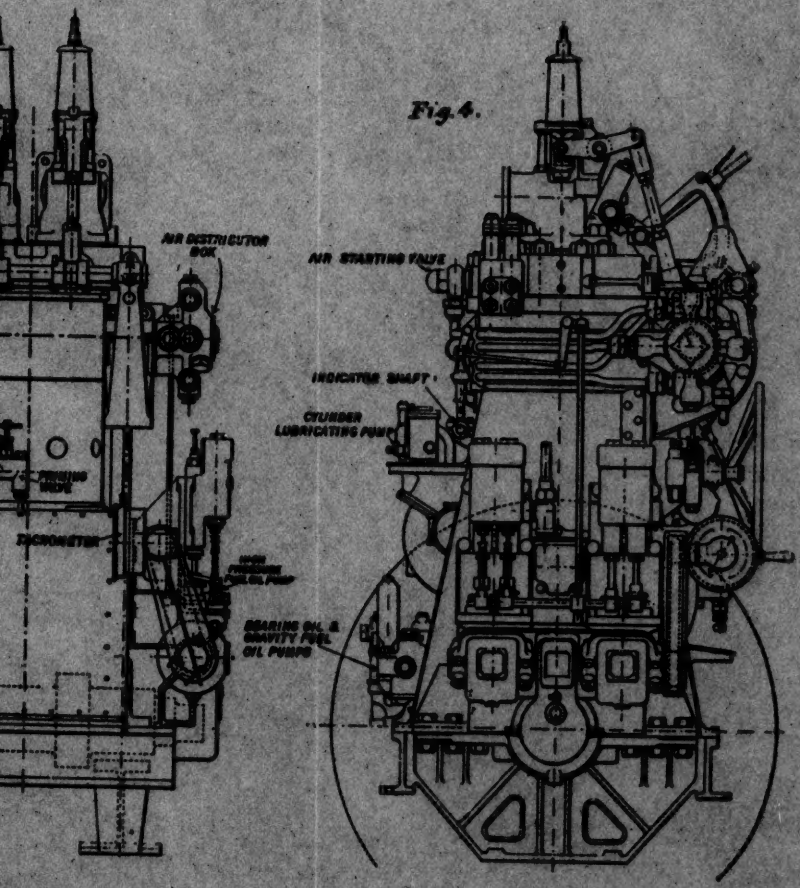

MANŒUVRING LEVER.
SPRAY VALVE
REVERSING WHEEL
ISOLATING VALVE & STRAINER
TACHOMETER
12"
11"
11"
12"
2'0"

Fig. 4.


AIR DESTRUCTOR BOX
AIR STARTING VALVE
INDICATOR SHAFT
CYLINDER LUBRICATING PUMP
TACHOMETER
BEARING OIL & GRAVITY FUEL OIL PUMPS

nected. A tendency is growing to accept separately-driven pumps in submarines, and if this matures the arrangement of any engine will be greatly simplified, the necessity of finding an accessible site on the engine for the auxiliaries presenting considerable difficulties where space is a primary consideration. The indicator shafts are also driven from the air camshafts. These consist of a shaft for each set of six cylinders, driven at engine speed, upon which are mounted adjustable eccentrics whose straps and rods move a vertical plunger at each cylinder to which the wire actuating the indicator is attached. A clutch with special tooth causes the indicator shafts to revolve when cards are to be taken. By this method the crank pits are kept clear of all parts likely to fail on long runs. A pair of small lubricators of plunger type are also fitted at the back of the engine. These supply oil to the pistons as previously described.

The induction header is not shown on the drawings, but it consists of a light steel pipe for each half of the engine, to which the induction valve boxes are coupled by trumpet-shaped pipes. The air to each header passes from the atmosphere through a bell-mouthed inlet, while a lead is also arranged to take a small air supply from the crank-case. This latter supply leaves the crank-case through a hole in each tie-plate and passes through a light fiber non-return valve on its way to the induction header. By this means the crank-case, which has small inlet grids at the ends of the engine and in the center, is maintained under a slight vacuum, and the atmosphere in the engine-room is not contaminated by the egress of vapor when running or after stopping.

The circulating water is led from an independent rotary pump to a main supplying the jackets, from which it passes to the cover through six tubes through the sandwich plate, the joint round these tubes being made by vulcanized rubber rings. It then passes to the jacket of the exhaust bend and away. The exhaust valves are fed from a separate main with a filter at either end. A short-circuiting valve is fitted between the pump suction and the cooling water discharge, so that in the event of a sudden dive to a great depth being made, the sea valves may be closed, and yet a circulation of the water in the closed system can be maintained till the engines have cooled.

The fuel oil flows from the gravity tank, which is placed in any convenient place in the engine-room, to the center of the engine, passing first through a settling pot where sediment and water can be removed, and then to the middle of a main running the length of the engine. This connection is so arranged that surging from end to end in a seaway is prevented, and from it the main rises towards each end facilitating venting and enabling a standard main to be used whether the rake of the engine in the boat is up or down. From this main small pipes with shut-off cocks lead to each high-pressure fuel pump, the fuel being filtered by a fine gauze filter embodied in the suction chamber of the pump. The pump itself, with its discharge filter, has been described above.

Examination of the drawings will show that all of the parts of the engine are particularly accessible, while in the construction ease of overhaul and adjustment has been carefully studied. To this and to the moderate rating of 1,200 brake horsepower to 1,400 brake horsepower, at 380 R.P.M. to 400 R.P.M., may be attributed the long and successful running that so many of the British boats have carried out without the necessity of assistance.

We are able to give, in Fig. 5, a copy of a typical indicator diagram from one of these engines, together with the record of a 6-hours' full

power trial (Table No. I) independently recorded, which will doubtless be of interest in view of the many discussions regarding the efficiency of solid injection.

TABLE I.—SIX HOURS' OFFICIAL SHOP TRIAL OF SCHNEIDER ENGINE 1,200 B.H.P. DATED SEPTEMBER 6, 1918.

Time.	R.P.M.	B.H.P.	Fuel Used.		Fuel Pressure.	Controls at		Circulating Water.	Lubricating Oil.			Atmosphere Temperature.
			Lb. per Hour.	Lb. per B.H.P.-Hr.		Fuel Pump.	Spray Valves.	Pressure.	Pressure.	Temperature, Fahrenheit. In.	Temperature, Fahrenheit. Out.	
					lb. per sq. in.			lb. per sq. in.	lb. per sq. in.	deg.	deg.	deg.
1st hour	379·6	1,209·6	451	0·381	4,500	9	18·5	10	12	67	97	61
2nd hour	382·5	1,218·5	451	0·379	4,500	9	18·5	10	12	71	101	63
3rd hour	382·0	1,218·0	451	0·380	4,500	9	18·5	10	12	72	106	64
4th hour	381·8	1,216·8	457	0·376	4,500	9	18·5	10	12	67	109	63
5th hour	381·4	1,215·0	479	0·394	4,500	9	18·5	10	12	68	110	63
6th hour	381·7	1,216·0	461	0·380	4,500	9	18·5	10	12	104	114	63
Average	381·3	1,215·0	463	0·381	—	—	—	—	—	—	—	—

Indicated horse-power, 1580.

Inspecting Officer's Report:—"The engine ran steadily and well, and no trouble of any sort was experienced throughout the trial. The crank pits remained clear of gases, and the exhaust was light and good. The trial is considered satisfactory."

Fig. 3 shows an eight-cylinder reversing engine in elevation, Fig. 4 giving an end view. A number of these engines were ordered by the Russian Government from Messrs. Vickers for patrol vessels. The cylinder dimensions are the same as in the twelve-cylinder engine, namely,

14½ inches diameter by 15 inches stroke, the engine easily developing 800 brake horsepower at 380 R.P.M. It will be noticed that the construction of the larger engine has been closely followed whenever possible, but in this instance the engine has been designed to operate on the common fuel pump or "rail" system. The fuel pumps are shown in the end view and are driven by spiral wheels from the end of the crankshaft. There are four plungers, 0.66 inch diameter by 1.25 inches stroke, the revolutions being 190 at full engine speed. Each pair of pumps can be isolated from the other or put out of action if required. A separate discharge is led to the control box in the center of the engine, so that if required one pair of pumps may serve one group of four cylinders. By these means, total stoppage in the event of failure of either pump or fuel main is prevented. As a matter of fact, these pumps, with their double-suction valves and forced lubrication are wonderfully reliable, while failure of fuel piping is almost unknown, the high pressure of sometimes over 4,000 pounds per square inch presenting no more difficulty than lower pressure in thinner piping.

The smaller hand wheel is free to be rotated when the reversing gear is in the full ahead or astern position. Its first turn opens a master valve in the control box which passes air to the air distributor boxes at the ends of the engine. These are similar in principle to those on the twelve-cylinder engine, but are disposed radially in a neat bronze casting, one cam only in the box being required for each direction of running. Further turns admit fuel to the main supplying first one group of four cylinders and then the remainder, the air being finally shut off. A last turn stops the engine by shutting fuel off the mains. The fuel passes through a strainer and a shut-off valve to the spray valve. Quick-closing shut-off valves are fitted in later engines of this type, the handle by its position serving as an indicator as to whether the supply is open to the spray valve. A small lever which may be seen at the running position is connected to the fuel pump, and by modifying the operation of the mechanically-operated suction valves in the usual manner, regulates the pressure of the fuel supply, and thence at any setting of the spray valve determines the amount injected.

The spray valve regulation is effected by the lever at the top of the engine in the middle. This lever rotates a shaft passing through bearings on each cover, the intermediate fuel levers being mounted on eccentrics, on this shaft. This intermediate lever is moved through the intermediary of a short tappet rod by the fuel cam on the single camshaft, which in this instance is mounted on brackets attached to the top of the columns and carries the inlet and exhaust cams also. The other end of this intermediate fuel lever depresses the bell crank of the spray valve, a roller in the lever sliding upon a hardened piece in the bell crank. The spray valve in these engines differs from that of the twelve-cylinder engine, the spindle being totally enclosed within a steel stamping and operated by a bell crank, the spindle of which passes through a gland in the side of the valve casing, a ball race taking the unbalanced fuel pressure on the bell crank. This design was chosen as lending itself better to the upper camshaft arrangement than did the standard valve.

The reversing of the engine is carried out by the large hand wheel, which, through a scroll and crank, first by partially turning a reversing shaft—mounted in the same bracket as the camshaft, but above it—swings the inlet and exhaust push rods clear of their cams and then, after sliding the camshaft till the reverse cam is in the correct position, replaces the push rods in their working position. This hand wheel is back-locked with the starting wheel so that it cannot be operated except when the latter is in the "stop" position. The fuel and air-starting cams being of small

lift can be pushed past their respective rollers without the latter being otherwise lifted, the cams and rollers being tapered to facilitate this operation.

TABLE II.—*Engine No. 521 Port. Official Starting and Reversing Trial, April 26, 1919.*

From.	To.	Condition of Engine.	Volume of Compressed Air in Use.	Air Pressure. Before.	After.	Difference.	Time to Start.	Revolutions to start.
			c. ft.	lb.	lb.	lb.	sec.	
Stop	Ahead	Cold	36·4	550	525	25	5	8·0
Stop	Ahead	Cold	36·4	525	510	15	3	4·0
Stop	Ahead	Cold	36·4	510	495	15	3	4·0
Stop	Ahead	Cold	36·4	495	485	10	3	4·0
Stop	Astern	Cold	36·4	480	465	15	2	3·0
Stop	Astern	Cold	36·4	465	450	15	2	2·5
Stop	Astern	Cold	36·4	450	440	10	2	2·5
Stop	Astern	Cold	36·4	440	425	15	2	2·5
Astern	Ahead	Slight Warm.	36·4	400	380	20	15	—
Ahead	Astern	Slight Warm.	36·4	380	365	15	16	—
Astern	Ahead	Slight Warm.	36·4	365	355	10	16	—
Ahead	Astern	Slight Warm.	36·4	355	345	10	15	—

Note.—Load condition as at full power.

The fuel system was primed by hand for the first start to approximately 400 lb. pressure. This was not necessary for the subsequent starts, as there was sufficient residual pressure in the system. For reversing no hand priming was carried out.

Of the time taken to reverse the engine, from 13 seconds to 14 seconds were absorbed in hand manipulation of shutting off and opening the controls and actuating the reversing wheel. Number of turns of reversing wheel from full ahead to full astern equals 23.

TABLE III.—*Engine No. 518 Port. July 3, 1918. Air Starting Trial Arranged for Lloyds Surveyor.*

Thirty-four starts were made, dropping the pressure from 450 lb. to 196 lb. per square inch. Volume of compressed air in use 37·5 cub. ft.

The engine was cold, not having been touched since the previous morning's preliminary air starting trial.

Load condition of engine as at full power.

Note.—The number of starts could have been increased, but the air bottles were some considerable distance from the engine, and due to the long length of pipe, considerable "wire drawing" took place.

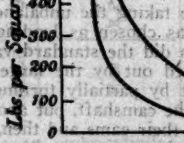


Fig. 5.

The drive for the camshaft in this engine is entirely by spur wheels, the sliding motion of the camshaft wheel being met by the provision of a wide wheel in the train. The bearing oil and gravity fuel pumps, together

with the usual indicator gear and piston oil pumps, are at the back of the engine in the center-bay. The two former pumps can be disconnected from the engine and worked by hand for priming purposes, a similar arrangement being followed in the twelve-cylinder engine.

Hand reversing was adopted instead of power gear on the ground of reliability after long service. Tables II and III, annexed, give the results of the starting and reversing tests, and incidentally show the rapidity of starting and the low consumption of air.

These engines gave great satisfaction to the Russians, but owing to the collapse of that country they did not receive them. A number were allocated to the Anglo-Saxon Petroleum Company, who used them for installation in some converted sailing ships. For this purpose, to suit the low speed of the ship, the propellers were designed to absorb 630 brake horsepower at 320 R.P.M., the engines being adjusted to suit. A number of these installations have been carried out, some in China, with satisfactory results.

These engines are interesting as showing a complete remodelling of type while maintaining interchangeability of important parts to a considerable extent. Attention to details in the re-design enable the weight of the reversing design to be brought below that of the eight-cylinder non-reversing design on which it was based, a few inches increase in overall length over the latter design having had to be taken to accommodate the reversing gear and central drive in the same bay.—"Engineering."

THE USE OF PULVERIZED COAL.

Under the auspices of the Fuel Research Board of the Department of Scientific and Industrial Research, Mr. Leonard C. Harvey, in the middle of last year, made a journey to the United States, in order to study the applications of pulverized coal to various uses in that country. On his return he made a report to the Board, which came to the conclusion that the information contained in that document would be of substantial value to the consumers of coal in British industries. It therefore published it as "Special Report No. 1," which is purchasable from agents for Government publications for the sum of 2s. 6d. net. Subsequently Mr. Harvey read before the annual meeting in May last of the Iron and Steel Institute a paper entitled "Use of Pulverized Coal, with Special Reference to its Application in Metallurgy," which was intended to form a supplement to the information contained in the report. Feeling sure that the matter will prove of interest to our readers, we propose to give in the following articles a summary of and extracts from these two documents. We may say before proceeding to do so, that both the report and the paper contain bibliographies of the subject, that in the former being the more comprehensive of the two.

At the outset it may be explained that Mr. Harvey visited twenty-three installations in which powdered coal was used commercially for, amongst other things, billet heating, puddling, ingot heating, tin-plating, annealing, steel, rivet heating, and reverberating melting furnaces, as well as for steam boilers, cement kilns, &c. He also investigated the following systems: The Quigley, Fuller, Holbeck, Muhlfeld, Pruden, Covert, Bergman, Aero, Kinyon and Stroud.

The report is divided into seven chapters, and has four appendices.

In Chapter I. Mr. Harvey, after quoting an article which appeared in the Engineering Supplement of "The Times," in February of last year, and which discussed the principles underlying the use of fuel in a pulverized form, first of all reviews in outline the several operations necessary

in order to obtain a sufficient degree of pulverization of the fuel. He then considers the range of fuels suitable for use in pulverized form, referring in succession to coke, pitch, anthracite, bituminous coals, lignite and peat.

In Chapter II. there is, first of all, a table which shows the original cost of pulverizing plants of varying sizes. It was compiled from figures furnished by the Fuller Engineering Company, of Church Street, New York, and gives in parallel columns the pre-war and estimated present-day costs of plants having outputs of from 10 to 250 tons per day. For our present purpose we need only concern ourselves with the prices now ruling. It appears that a plant, with a capacity of from 10 to 40 tons per day, is estimated to cost £9687, and will necessitate the use of one 33-inch mill. A plant capable of turning out from 50 to 90 tons per day will cost £11,562 and will require one 42-inch mill. A 100 to 130-ton plant will cost £14,062, and will need three 33-inch mills; a 140 to 180-ton plant, having two 42-inch mills, will cost £15,625; while a 190 to 250-ton plant with three 42-inch mills, will necessitate an outlay of £19,375.

As regards the cost of pulverizing the coal Mr. Harvey quotes the experience of three separate works. In the first case the possible output of the works was 80 tons and about 30 tons were actually produced. In the second case the capacity was the same—80 tons—and the output from 30 to 35 tons, while in the third the full capacity was 50 tons, and about 30 tons were produced. In case No. 1 the outgoings taken into account were for oil and grease, waste, stores and fuel for drying, labor, current at "0.02 cent"—evidently a mistake for dollars—or about 1d. per kilowatt-hour, machine shop charges, interest and taxes. The total cost, taken over a period of one month, worked out at 2.21 dols., or, say, 9s. 2½d. per ton. In case No. 2 the operating costs given include labor and labor insurance, stores, electric repairs, machinery repairs, engineering repairs, and electric power at 0.018 dols. No allowance was therefore made for interest and depreciation. The cost averaged over a period of six months 1.48 dols., say, 6s. 2d. per ton. If, however, interest and depreciation at per cent on £11,562—the average cost of a plant to produce from 50 to 90 tons per day—be added, the total cost works out at 2.34 dols., or 9s. 9d. per ton. In case No. 3 the items taken included direct labor; repairs, labor; repairs, material; supplies, waste, &c.; insurance; and on-charges, and the total arrived at, as the average taken over a month's working, was 2.25 dols., or, say, 9s. 4½d. per ton. As a matter of fact, this total was higher than it would ordinarily be because during the month there was an unusual expenditure on repairs, &c., and the normal cost is given as being more nearly 1.489 dols., or, say, 6s. 2½d. per ton. Taking this lower cost the average for the first three plants works out at 2.013 dols., or just over 8s. 4½d. per ton of pulverized coal delivered to the furnaces.

The foregoing figures relate to present-day costs. For purposes of comparison Mr. Harvey gives the cost during the year 1913, and therefore before prices were influenced by the war, of a considerably larger plant, which had a full capacity of 150 tons a day, and the output of which was 140 tons per day. The costs for fuel for drying, operating, power—steam and electric—repairs to machinery, and repairs to buildings, came out at 0.602 dols., or just over 2s. 6d. per ton. Dividing 14 per cent on the capital outlay of £10,417 by the total yearly production—42,000 tons—and adding the result to the 2s. 6d., the figure of just over 3s. 2½d. per ton is arrived at. This figure is not strictly comparable with those of the first three plants, since, whereas two of them were working very considerably below their full capacity, and the third at only 60 per cent of its full capacity, plant No. 4 was producing over 93 per cent of the quantity for which it was designed. However, the items of cost, which in all

cases are given in detail, will doubtless prove to be useful guides as to past and present costs in the United States under the specific conditions mentioned.

The report then goes on to outline the various processes through which the coal passes in standard mill-house practice in American installations before it becomes pulverized fuel. The run of mine, lump coal or screenings, are delivered alongside the pulverizing mill in railway trucks, fitted preferably with bottom dumping doors, so that the coal may be discharged into track hoppers. From the latter the coal passes first of all to a crusher, in order that it may be broken down so as to pass through a screen of ¾-inch mesh, and is taken thence to the crushed coal bin, past a magnetic separator. From the crushed coal bin the coal descends by gravity to the dryers, which are thus referred to by Mr. Harvey: "Dryers of several efficient types are in use. They are heated by means of hand-fired grates, mechanical stokers, or pulverized coal burners. The hot gases from the furnaces are sometimes passed directly over and in contact with the coal, or through a central tube to the end of the coal-drying cylinder, and thereafter returned along the outer space in contact with the coal, or again, a compromise is made between these two systems. For the latter case, the hot gases first come in contact with the outer shell of the dryer to about half-way along its length; they are then collected and transferred to the end of the cylinder where they enter into direct contact with the coal as the gases pass back through the cylinder to the furnace end, where they escape to the dryer chimney. As a rule the dryers are rated to comply closely with the maximum capacity of mills operating. Crushers are generally started up in advance of the pulverizing mill, and are run for a short time after the mills are closed down. In this way a sufficient amount of dry coal is available when the mills are started up. Coal should be dried to within one per cent moisture, about 10 per cent moisture being extracted at each passage of the coal through the dryer. When fuel contains a heavy percentage of water the coal can be passed through the dryer a second time." From the dryers the coal is taken to the top of the building by an elevator and delivered into the dry coal bins.

In addition to the several types of grinding mills used in cement works, the mills generally installed in American steel works are the "Fuller," the "Raymond," and the "Bonnot." The two last mentioned are ordinarily run with air separator fans. The Fuller mills have only been equipped with them comparatively recently. When they are not fixed the pulverized coal as it comes from the discharge spouts is taken up to the top of the mill-house by means of bucket elevators. The advantage of air-separation exhaust from the mills lies in the direct delivery of the coal dust to the bins without having to employ elevators. Moreover, there are the additional advantages of simplicity of plant, absence of dust leakage through crevices in the mills, and absence of dust from the elevator casing, because the elevator is non-existent, while, as a consequence, there are no repairs of the elevator to pay for. On the other hand, the total power for grinding and delivering the coal by air-separation is somewhat greater than that required to run screen mills and bucket elevators. Further than that, the coal dust must pass through the suction fan at high speed, with the result that the blades are rapidly worn, and it is necessary, moreover, to install cyclone separators to deposit the coal dust from the air current. Summing up, Mr. Harvey remarks: "With the exception of power absorbed, the advantages of one method seem almost to balance those of the other."

The standard of fineness that has been adopted throughout the United States for industrial coal dust plants is 85 per cent through a 200 mesh

screen—40,000 holes to the square inch—and 95 per cent through a 100 mesh screen—10,000 holes to the square inch. The coal as it leaves the dryer before grinding should not contain more than 1 per cent of moisture.

In Chapter IV. Mr. Harvey discusses the various methods of transporting the coal dust to the burner under the following headings:

(*a*) By screw conveyors.
(*b*) By the air pressure system.
(*c*) By the air mixture system.
(*d*) By the enclosed pipe cable system.

With regard to (*b*) it is explained that it was patented in 1916 by Messrs. Magarvey, Salton and Heisler, and that the process, which has been of late quite extensively adopted, is controlled by the Quigley Furnace Specialties Company, of 26, Courtland Street, New York City. In it what are called "Blowing Tanks" are installed in the mill-house. Compressed air is applied to these tanks for the purpose of forcing any given quantity of coal through small supply pipes to bins at the furnaces. The tanks are arranged on weighing platforms, so that the weight of coal delivered into them can be read off on scale dials. The coal dust travels through ordinary 3-inch or 4-inch screwed piping to the bins at the furnaces. In view of stoppage caused by moisture in the coal, or due to condensation within the conveying pipes, a small companion pipe with tappings into the coal delivery pipe is provided. From it compressed air can at any time be supplied through the tappings or "bleeders," as the makers have termed them, and any stoppage of coal broken up and cleared. Mr. Harvey remarks, concerning the system, that the advantages pertaining to it are considerable. By it the coal dust can be transported through relatively small pipes and normal bends, which can be led overhead or underground with just the same convenience as can water or gas pipes. An ingenious accessory to the system, designed for the semi-automatic feeding of coal dust to any number of bins throughout the works, is also discussed.

The "air mixture" method is that employed in the Holbeck patented system, which is controlled by the Bonnot Company of Canton, Ohio. In it the coal dust is mixed at the mill-house with approximately half the quantity of air required for its complete combustion. Supply is effected at a pressure of 10/12 ounces per square inch, and a speed of 90 feet per second through the main supply pipes to the branch service at the furnaces is reached. The main supply pipe makes a complete loop from and to the mill-house, at which point the returning coal is extracted in a cyclone separator and re-delivered to the pulverized storage bin. In cases in which long lengths of main supply piping have to be used—say, in a loop of 3,000 feet—probably one or two booster fans would be employed.

The "enclosed pipe cable system" consists of a complete circuit of delivery pipe inside which is run a central cable fitted with discs for the conveyance of the coal dust along the supply circuit. Side outlet discharge openings controlled by shut-off valves are provided at the points where the fuel is to be used. The system, Mr. Harvey explains, is only in the experimental stage, and will probably be confined to relatively short delivery distances.

On the question of spontaneous combustion Mr. Harvey observes that it is sound practice not to store more than forty-eight hours' supply of dried coal. Spontaneous combustion is not likely to occur in that time providing that the coal as delivered from the drier is not overheated. The temperature at which it leaves that apparatus should ordinarily not exceed 200 degrees Fah., but the permissible temperature depends upon the nature of the coal and its ash. Not more than a twenty-four hours'

supply of pulverized coal should be stored on the mill-house, and it is considered advisable to store only sufficient coal in the furnace bin to last for one shift—eight hours or so. It would not appear, however, that much difficulty has been experienced in America from spontaneous combustion in the mill-house. Mr. Harvey mentions cases in which as large a bulk as from 30 to 40 tons of pulverized coal had been stored for three or four weeks without any sign of spontaneous combustion. In the neighborhood of the furnace, too, bins holding 10 to 15 tons of pulverized coal have been known to remain charged for three or four weeks without ignition. On the other hand, fires have occasionally occurred overnight. The only effect of spontaneous combustion is, apparently, to produce a slight caking in the center of the bulk. The actual fire is ultimately self-extinguished in the absence of sufficient oxygen to support combustion and by the generation of carbon dioxide gas.

As regards explosions, Mr. Harvey states that at none of the works that he visited was it found that any special precautions had been taken against explosion of the coal dust other than those dictated by common sense. "Installations," he remarks, "had been in use without any explosion having taken place for so many years that the danger of explosion had almost been forgotten." In some of the older plants mills, bins, girders, stairs, elevators, &c., were thickly coated with coal dust, and, remarks Mr. Harvey, "an unnecessary risk of fire, if not of actual explosion, is being courted in several plants." However, he continues, "the existence of such conditions in the mill-house for years without mishap should reassure those who are excessively fearful of coal-dust explosions." At new plants apparently greater attention is being given to keeping the mills and mill-house clean, and Mr. Harvey adds, "In fact, the new types of mills and the care now given to design of plant makes for a dust-tight equipment." In storing powdered coal the following precautions are recommended: (1) Limit the height of the coal pile to 10 feet or 12 feet; and (2) isolate the coal from all sources of heat such as steam pipes, flues, reflecting surfaces and direct sunlight.

In Chapter V. illustrations—which we reproduce—are given of the Quigley, Lopulco, Bergman and Fuller and Pruden burners. It is explained that the present tendency is to use low-pressure air supply for mixing with and introducing the coal dust into the combustion chamber or furnace, thus allowing the particles of ash to settle out before reaching the work to be heated or the boiler tubes and surfaces. Burners are therefore, says Mr. Harvey, not as a rule of a complicated nature, and more often than not the coal dust is simply allowed to fall by gravity from the feed screw into a single pipe, which carries the air for the combustion of the fuel. The pressures used vary from 2 ounces up to 6 ounces per square inch, but the lower the pressure the better. One form of Quigley burner—see Fig. 1—has a double air supply, provided from one source. The primary air has an ejector action upon the supply of powdered coal. The initial mixture of coal dust and air is then introduced into the main air supply just prior to its entry into the furnace. The pressure of the air supply at the point of entry of the fuel is about 2 ounces to 3 ounces.

The Fuller burner—see Fig. 3—usually consists of a single air pipe or burner tube into which the coal dust falls by gravity from the screw feeder. The pressure of the air supply is generally 2 ounces per square inch.

The Bergman burner—see Fig. 5—is fitted with an internal cone arranged concentrically within the air supply pipe, and the coal dust is fed in by gravity in such a manner that it forms a complete film or

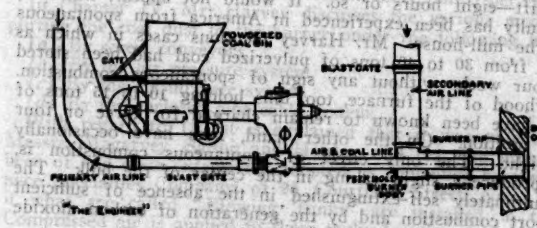


FIG. 1.—ONE FORM OF QUIGLEY BURNER

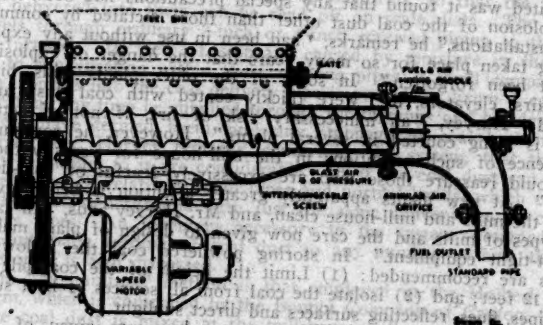


FIG. 2.—THE LOFVLOD BURNER

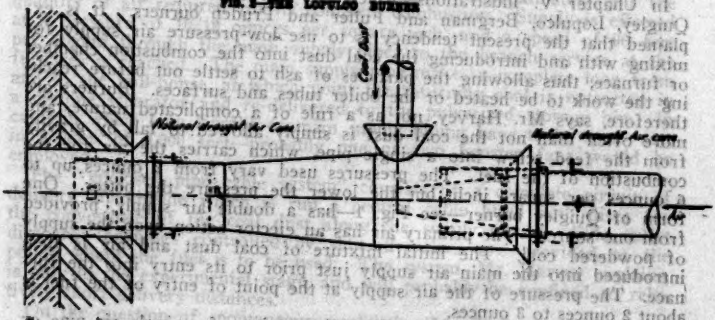
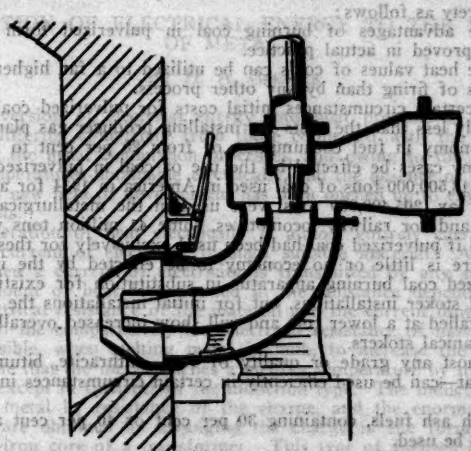


FIG. 3.—THE FULLER BURNER

coating to the air jet, the purpose being to introduce the air into the furnace in the center of a covering of fuel. It is contended, says Mr. Harvey, that when coal dust is fed into the center of the air jet the latter expands away from the pulverized fuel and an imperfect mixing of the air and fuel in the furnace results.

The "Lopulco"—see Fig. 2—or Locomotive Pulverized Fuel Company's mixer, is combined with the screw feeder. The burner consists only of the pipe through which the mixed coal and air is conducted to the furnace. In practice, air is supplied at 6 ounces to 8 ounces pressure and enters the jacket surrounding the delivery end of the screw feed. At that point the mixed coal and air is given a whirling motion by means of the paddle blades, which assists the intimate mixing of the fuel and air for combustion. From the combination feeder-mixer a number of burner tubes can be supplied.



"The Engineer" Swain &c.

FIG. 5—THE BERGMAN BURNER.

With regard to other burners, Mr. Harvey states that the Heyl and Patterson Company, of Pittsburgh, which controls the "Covert" system, has several types of burners or mixers, one of them being of special interest. Into it the coal dust falls in the usual manner by gravity and descends on to diaphragm shelves projecting one below the other and fitted horizontally across the air inlet pipe or burner tube. Air is supplied at 2-ounce or 3-ounce pressure and picks up the coal dust on passing between the shelves. All the feeders hitherto referred to, with the exception of those of the Quigley type, operate with variable-speed motors for the control of the supply of coal dust to the burners. The Quigley feeder is fitted with adjustable jaws, through which the coal dust is passed to the burner. The feed screw can therefore rotate at a constant speed.

Finally, reference is made to the "Pruden" carburizer or mixer supplied by the Powdered Coal Equipment and Engineering Company, of Chicago. The apparatus effects, according to Mr. Harvey, perhaps the most perfect mixture of coal dust with air. The powdered coal, as it is withdrawn by a screw feeder from the bunker, is mixed with a primary supply of air and the mixture is then conveyed to a second chamber, in which the balance of air required for combustion is introduced into the primary mixture.

Chapter VI., which contains the opinions of numerous users of powdered coal fuel, applications of the system, working results, &c., is already in so condensed a form that it is practically impossible to compress it further. It is full of valuable and instructive matter, however, and those interested in the question of powdered coal fuel will be well repaid by obtaining a copy of the report and reading it *in extenso*.

Chapter VII., which deals with Mr. Harvey's conclusions, we reproduce in its entirety as follows:

(1) The advantages of burning coal in pulverized form have been definitely proved in actual practice.

(2) The heat values of coals can be utilized to a far higher degree by this means of firing than by any other process.

(3) In certain circumstances initial costs for pulverized coal plants are considerably less than the costs for installing producer gas plants.

(4) Economy in fuel consumption of from 20 per cent to 50 per cent can in many cases be effected by the use of coal in pulverized form.

Of the 518,500,000 tons of coal used in America in 1914 for all purposes, of which, say, 205,400,000 tons were used in the metallurgical and steel industries and for railway locomotives, some 41 million tons would have been saved if pulverized coal had been used exclusively for these purposes.

(5) There is little or no economy to be effected by the introduction of pulverized coal burning apparatus in substitution for existing efficient mechanical stoker installations, but for initial installations the latter plant can be installed at a lower cost and will show increased overall economies over mechanical stokers.

(6) Almost any grade or quality of fuel—anthracite, bituminous, lignite, or peat—can be used efficiently in certain circumstances in pulverized form.

(7) High ash fuels, containing 30 per cent or 40 per cent ash, can in some cases be used.

(8) Large quantities of what is considered waste coal can be used to good purpose, and culm and slack heaps at mines can be at once turned to profitable account.

(9) In suitably designed plants there is practically no danger whatever of the possible explosion of coal dust.

(10) With the precautions as to limited storage recommended, spontaneous combustion introduces no apparent difficulties.

(11) That the slag or dust resulting from the ash in coals can be conveniently and effectively handled and removed from all classes of melting and heat treatment furnaces, stationary boilers and locomotives, small furnaces such as rivet-heating furnaces being an exception.

(12) A very important start has been made in connection with the firing of large powerhouse boiler plants by this means, and its extension in this direction is likely to develop rapidly.

(13) In view of the attention now being given to marine boiler firing by this means, useful and important results are to be expected.

(14) Owing to the very considerably reduced amount of labor incidental to a pulverized coal plant as compared with hand firing and, in certain

cases, stoker firing, the labor saving is a most important feature introduced by this system of burning coal.

Saving in labor is particularly marked in connection with the firing of railway locomotives by this means.

(15) In view of the smokeless combustion of pulverized coal in metallurgical furnaces, and especially in the steel industries, for boiler firing and for locomotives, the abatement of smoke nuisances in large cities by this means can be accomplished to an appreciable extent.

Appendix I. gives a list of the systems investigated in the United States by Mr. Harvey, with the addresses of their proprietors. Appendix II. is devoted to a list of installations visited, with brief details in each case of the particular direction in which powdered fuel is applied. Appendix III. contains a fairly extensive list of powdered fuel users, while Appendix IV. embodies the Bibliography.—"The Engineer."

APPLICATION OF ELECTRICAL ENERGY TO THE MELTING OF METALS.*

By H. A. Greaves.

The conversion of electrical energy into heat presents a number of problems differing completely from those connected with the production of heat by the usual combustion processes, and owing to the almost unlimited temperatures obtainable electrically, and the absence of combustion products, a new field of development has been opened up to engineers and metallurgists.

The generation of heat electrically is almost entirely carried out by passing a current of electricity through suitable material. As everyone knows, when a current of electricity is transmitted by any substance, a certain amount of heat is generated in the substance depending mainly on the electrical resistance of the material and the current flowing.

Owing to the comparatively low electrical resistance of most metals, it is not feasible, when melting metal in bulk, to increase the current to such a value that the metal reaches a melting temperature by its resistance loss only, except in furnaces of the induction type. The induction furnace melts the metal by resistance of the charge, and the enormous current necessary are obtained by arranging the charge in the form of a ring round the iron core of a transformer. This type of furnace is not commercially satisfactory, owing to—

1. The loss in efficiency caused by the metal being in the form of a ring, and therefore extremely high heat losses occur.

2. "Pinch" effect, or the breaking of the circuit if the current exceeds a certain value, this effect being due to the mutual attraction of parallel conductors.

3. The electrical conditions of the induction furnace are unsuited to normal power-supply circuits; a bad power factor is obtained very low frequency is required, and the furnaces are usually designed to operate on single-phase supply only.

It is necessary, therefore, to use for the generation of heat a resistant material other than the metal to be melted, and the electric arc, which is a column of gas or vapor through which a current of electricity is passing, provides a ready and efficient method of generating a very intense heat in a small space.

*Paper read at a joint meeting of the Institution of Electrical Engineers and the Iron and Steel Institute, Thursday, May 8, 1919.

The most efficient method of utilizing the heat of the electric arc is obviously to make the material to be melted one pole of the circuit, or, at any rate, part of the circuit, in order that the arc may be in direct contact with the metal. The first furnace using the electric arc was designed with the container as one pole of the circuit, and a carbon electrode over the metal as the other pole of the circuit.

In order to use a higher voltage and obtain a better distribution of heat, a furnace was designed with two carbon electrodes over the charge, the current passing from one electrode to the charge, and from the charge to the other electrode, single-phase current being used, as shown diagrammatically in Fig. 1.

In order to utilize three-phase currents, a third electrode was arranged over the charge, as in Fig. 2; furnaces of this kind have been very largely adopted in connection with steel furnace practice, and still form a considerable proportion of the furnaces in operation at the present time.

Without in any way attempting to deprecate the extensive pioneer work carried out by furnaces of this type, there are several inherent disadvantages, viz.:

1. The electrode currents are not independent of each other.
2. The heat is applied to the surface of the charge only, and very little circulation of metal is caused.

With regard to (1) it will be seen that if one electrode dips into the charge, or is being driven down into the charge by automatic regulation, while the other electrodes are clear, no current passes and the electrode or electrode-operating gear is liable to be broken while a molten charge of steel takes up carbon from the electrode and upsets the analysis. Many devices have been introduced to overcome these objections, but it is well known that most users experience difficulties of this kind, and particularly so when the furnace has an acid or non-conductive lining.

With regard to (2), it will be generally acknowledged that it is more efficient to boil water by applying a gas burner below the water than on the top surface only, as very little circulation of water will result in the latter case. This applies also in the case of an electric furnace, and it is a great advantage to introduce a method of causing the metal to circulate freely.

This circulation can be effected by making the hearth of the furnace fairly thick and passing a considerable current through it by using it as one electrode; it is possible in practice to apply from 8 per cent to 10 per cent of the total energy supplied to the furnace on the hearth alone, by using a mixture of magnesite and dolomite and grading it to give the highest resistances near the charge and a negligible resistance towards the outside. Such a hearth is as strong and permanent as any basic hearth that can be made.

Some years ago, in collaboration with Mr. Etchells, the author discovered an electrical law which enables three-phase or two-phase current to be applied to a furnace with an unequal resistance in one of the phases and still maintain a truly balanced load as regards both power and power factor on the primary phases. The connections of such a furnace are shown for three-phase and two-phase working in Figs. 3 and 4, respectively, the length of O C being determined by the resistance of the furnace hearth.

In passing, it may be of interest to electrical engineers to know that an arrangement, as shown in Fig. 5, with an unequal primary star and an unequal secondary delta connected to the furnace will give a truly balanced primary load when the two electrodes are carrying equal currents, the transformer ratios varying according to the relative resistance of the furnace hearth to that of one of the arcs. The author purposely avoids giving mathematical treatment of these rather curious electrical combinations, as they would not interest many of the members.

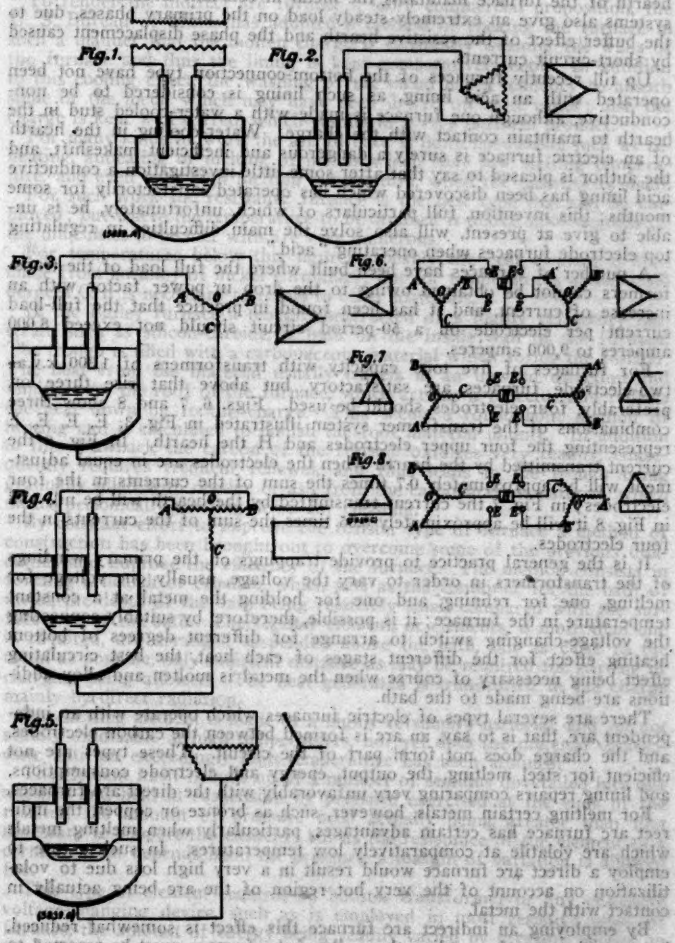


Fig.1.
Fig.2.
Fig.3.
Fig.6.
Fig.7
Fig.8.
Fig.4.
Fig.5.

It will readily be seen that with the systems shown in Figs 3, 4 and 5, each electrode is independent, and regulation of the electrodes, either automatically or by hand, is perfectly simple, while the heat generated in the hearth of the furnace maintains the metal in constant circulation. These systems also give an extremely steady load on the primary phases, due to the buffer effect of the resistive hearth and the phase displacement caused by short-circuit currents.

Up till recently furnaces of the bottom-connection type have not been operated with an acid lining, as such lining is considered to be non-conductive, although one furnace is made with a water-cooled stud in the hearth to maintain contact with the charge. Water-cooling in the hearth of an electric furnace is surely a dangerous and inefficient makeshift, and the author is pleased to say that after some little investigation a conductive acid lining has been discovered which has operated satisfactorily for some months; this invention, full particulars of which, unfortunately, he is unable to give at present, will also solve the main difficulties in regulating top electrode furnaces when operating "acid."

A number of furnaces have been built where the full load of the transformers cannot be obtained owing to the drop in power factor with an increase of current, and it has been found in practice that the full-load current per electrode on a 50-period circuit should not exceed 8,000 ampères to 9,000 ampères.

For furnaces of five tons' capacity with transformers of 1,300 k.v.a., two-electrode furnaces are satisfactory, but above that size three or, preferably, four electrodes should be used. Figs. 6, 7 and 8 show three combinations of the transformer system illustrated in Fig. 3, E, E, E, E representing the four upper electrodes and H the hearth. In Fig. 6 the current transmitted by the hearth when the electrodes are in equal adjustment will be approximately 0.7 times the sum of the currents in the four electrodes; in Fig. 7 the current transmitted by the hearth will be nil, and in Fig. 8 it will be approximately 0.35 times the sum of the currents in the four electrodes.

It is the general practice to provide trappings on the primary windings of the transformers in order to vary the voltage, usually one voltage for melting, one for refining, and one for holding the metal at a constant temperature in the furnace; it is possible, therefore, by suitably connecting the voltage-changing switch to arrange for different degrees of bottom heating effect for the different stages of each heat, the best circulating effect being necessary of course when the metal is molten and alloy additions are being made to the bath.

There are several types of electric furnaces which operate with an independent arc, that is to say, an arc is formed between the carbon electrodes, and the charge does not form part of the circuit. These types are not efficient for steel melting, the output, energy and electrode consumptions, and lining repairs comparing very unfavorably with the direct arc furnaces.

For melting certain metals, however, such as bronze or copper, the indirect arc furnace has certain advantages, particularly when melting metals which are volatile at comparatively low temperatures. In such a case to employ a direct arc furnace would result in a very high loss due to volatilization on account of the very hot region of the arc being actually in contact with the metal.

By employing an indirect arc furnace this effect is somewhat reduced, but special means for cooling the walls of the furnace must be resorted to in order to prevent the refractories from fusing at too high a rate and thus render the cost of running prohibitive.

The reason for this is that the rays of intense heat from the arc strike directly on the walls, whereas in the direct arc furnace the intense heat is

more or less shielded by being partly buried in a crater of slag or metal, which material, in addition to acting as a shutter, also rapidly conveys the heat away.

To render the indirect arc furnace a more commercial proposition, the U. S. Bureau of Mines has adopted a method of rocking the furnace in such a manner that the molten charge is constantly washing the walls of the furnace and thus the lining is kept comparatively cool. In addition to this cooling effect, the washing of the metal has a tendency to absorb some of the metal which may have been driven off as a vapor; also the charge is kept well stirred, which results in a very uniform product.

For many kinds of work the arc furnace is quite unsuitable, such as reheating, annealing or melting of metals which have low melting temperature, and even with high melting temperature, when the quantity is small.

For such work the resistance furnace is the best type that can be employed; but where the temperature to be attained is above 1,000 degrees C., the difficulties to be met with are very numerous.

For temperatures below this figure, probably the best element is that made from an alloy of nickel chromium; but for temperatures above 1,000 dergees C. it is necessary to resort to other materials.

In the Bailey furnace a trough constructed of a highly refractory material, such as silicon-carbide, is built on the inside wall of the furnace. The trough is filled with a carbonaceous material which forms the resister. The heat from the material usually travels in an upward direction and impinges on the roof of the furnace, which acts as a reflector and reflects the heat down on to the charge. This seems a roundabout method of heating and is calculated to punish the roof material unduly. In addition to this drawback the carbon of the resister oxidizes very readily, consequently requires frequent renewal, and thus leads to the trough being gradually filled with residue or ash from the carbonaceous material, which means periodically shutting down for cleaning.

By constant effort to improve the resister type of furnace a method of construction has been brought out to overcome some of the previous difficulties and improve the efficiency of the furnace. The method consists in forming a hearth or crucible, which acts as the container for the bath of metal, the depth of the bath being relatively small compared with the surface area of the bath. The register element, or elements, if more than one is required, are arranged suspended above the bath, but as close to the metal as possible, only sufficient distance as may be required for stirring or charging being allowed. The heat generated is transmitted to the charge mainly by direct radiation.

The heating element is made of a highly refractory material, and yet not readily oxidizable at high temperatures, nor yet does the material disassociate until an exceedingly high temperature has been attained.

The element itself is built up of a number of sections dovetailed into one another and held in suspension by pressure exercised at the ends of the resister, the amount of pressure used actually being greater than that necessary to support the element; but as the resistance of the element to a certain extent depends upon the pressure, a margin of variation is allowed for.

This type of element requires no booster transformer or any extensive voltage-changing device, such as is employed in most resistive types of furnace, the amount of energy being readily varied by pressure applied to the heater unit in a manner external to the furnace.

Another feature of the furnace is that the elements are renewable even while the furnace is hot

The construction is such as to make the furnace gas-tight, which results in an absolute minimum of zinc loss when employed on brass melting.—"Engineering."

REPAIRS TO THE *CURACA*.

An Echo of the Halifax Explosion.

In the reconstruction of the British steamer *Curaca* the Robin's Dry Dock & Repair Company has again demonstrated its ability to handle successfully difficult jobs sent to its big plant in Erie Basin, Brooklyn.

The *Curaca* was sunk during the explosion in Halifax Harbor. Her superstructure was blown away and she was buckled at about the mid-length to such an extent that when refloated the draught at buckle was 16 feet 2 inches, while the draught at bow was 7 feet and at stern 9 feet 8 inches, showing that the vessel was forced up 9 feet 2 inches from the base line forward while the stern was forced up 6 feet 6 inches.

In this condition the vessel was raised, temporarily repaired and brought to New York under her own steam, and the work of straightening and repairing commenced on April 25.

The big problem here was to restore the vessel to an even keel. On a preliminary survey this seemed to be impossible. Further examination was made and finally Mr. George J. Robinson, Vice-President of the Company, outlined a plan which subsequently proved successful. His report on the job is of more than ordinary interest and value and reads as follows:

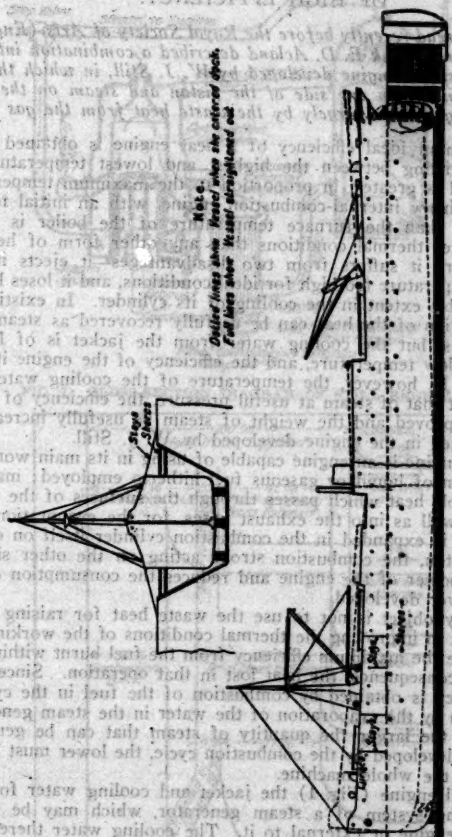
"We decided to use No. 2 graving dock for the *Curaca*. Keel blocks were set solid for a length of 36 feet, as it had not been determined exactly where the buckle was. On April 25 the vessel was warped in, placed over the blocks and plumbed up. Shores from each side of the dock were then put in place against the sides of the vessel. Wire hawsers were extended from each side of the deck and made fast ashore, so that there would be no danger of either the forward or after section listing if a break should result at the buckle point before the straightening of the vessel was completed.

The dock pumps were then started. As soon as the buckled area of the keel touched the blocks the pumps were stopped and examination made to see that the vessel was perfectly upright and over the blocks. The sides of the vessel were then gradually cut at the buckle from the deck to the water-line on both sides. The pumps were again started and as the dock was slowly freed from water the cutting was continued about 6 inches at a time.

Close observation showed that as the cutting of the plates and the pumping away of the water progressed the ends of the *Curaca* dropped gradually, being without the support of the blocks. During this operation frequent inspections were made to determine that both the forward and after sections were upright, that the hull had not twisted and that no structural change had resulted. When the dock had been pumped dry the entire keel of the *Curaca* rested on the blocks.

This operation was begun at 7:30 a. m. and was successfully completed at 3 p. m. the same day.

We found that the bottom plating around the buckle had fractured, due, probably, to the vessel having worked at this point. The bottom of the *Curaca* was also damaged by the explosion to such an extent that 54 of her bottom plates needed repairing and renewing."—"Shipbuilding and Shipping Record."


Note.
Outline lines show Vessel when she entered dock.
Full lines show Vessel straightened out.
Stage Sheers
Sheers
Sheers
How the "Ouragan" was Straightened Out.

COMBINATION INTERNAL-COMBUSTION AND STEAM ENGINE OF HIGH EFFICIENCY.

In a paper read recently before the Royal Society of Arts (England) and abstracted here, Frank E. D. Acland described a combination internal-combustion and steam engine developed by W. J. Still, in which the products of combustion act on one side of the piston and steam on the other, the steam being generated largely by the waste heat from the gas cycle.

The maximum ideal efficiency of a heat engine is obtained where the difference existing between the highest and lowest temperatures of the working fluid is greatest in proportion to the maximum temperature, and here the ordinary internal-combustion engine, with an initial temperature often higher than the furnace temperature of the boiler is capable of realizing better thermal conditions than any other form of heat engine; but in its turn it suffers from two disadvantages—it ejects its working fluid at a temperature too high for ideal conditions, and it loses heat energy to a regrettable extent in the cooling of its cylinder. In existing engines some proportion of the heat can be usefully recovered as steam from the exhaust gases, but the cooling water from the jacket is of little value, owing to its low temperature, and the efficiency of the engine itself is not augmented. If, however, the temperature of the cooling water could be maintained at that of steam at useful pressure, the efficiency of the engine would be improved and the weight of steam be usefully increased. This is accomplished in the engine developed by W. J. Still.

The Still engine is an engine capable of using in its main working cylinder, any form of liquid or gaseous fuel hitherto employed; makes use of the recoverable heat which passes through the surfaces of the combustion cylinder, as well as into the exhaust gases, for the evaporation of steam, which steam is expanded in the combustion cylinder itself on one side of the main piston, the combustion stroke acting on the other side. It increases the power of the engine and reduces the consumption of the fuel per horsepower developed.

Its primary object is not to use the waste heat for raising steam, but first to use it in improving the thermal conditions of the working cylinder, and so insure the maximum efficiency from the fuel burnt within it, diminishing, as a consequence, the heat lost in that operation. Since the maximum efficiency is obtained by combustion of the fuel in the cylinder and the minimum by the evaporation of the water in the steam generator, it is evident that the larger the quantity of steam that can be generated per horsepower developed by the combustion cycle, the lower must be the heat efficiency of the whole machine.

In the Still engine (Fig. 1) the jacket and cooling water form part of the circulating system of a steam generator, which may be an integral part of the engine or external to it. The cooling water therefore enters and leaves the jacket at a constant temperature, regulated by the pressure of steam, the cooling being effected by converting the water into steam without raising its temperature. Excluding the radiation losses, which are kept low by lagging, all the heat which passes through the walls is thus usefully recovered in the water as steam. The temperature of the cylinder wall is uniform over the whole of its exterior surface, and the heat lost to the cooling water at each stage of the cycle—compression, combustion and expansion—is diminished.

During compression, owing to the walls being at steam temperature, the incoming charge picks up heat, instead of losing it, during the greater part of the stroke, an advantage of the greatest value to the heavy-oil types of Still engines, where an air charge is taken in at the full outstroke, and is

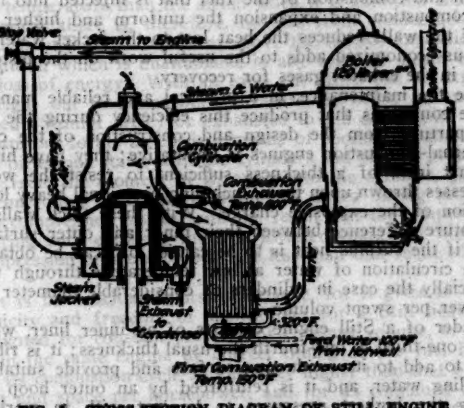


FIG. 1. CROSS-SECTION DIAGRAM OF STILL ENGINE

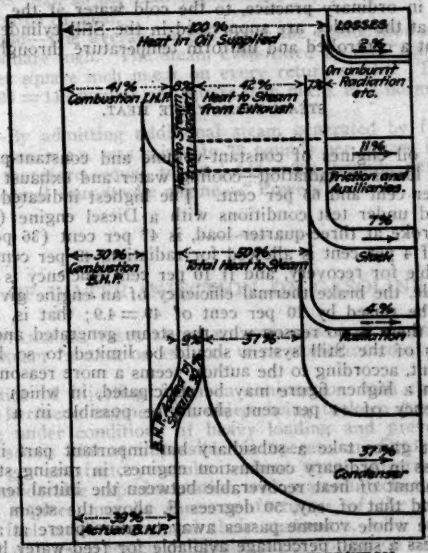


FIG. 2. CHART SHOWING DISTRIBUTION OF HEAT UNITS

compressed to a pressure where its increased temperature insures the certain ignition and combustion of the fuel that is injected into it.

During combustion and expansion the uniform and higher mean temperature of the walls reduces the heat lost to the jacket water. Some of the heat thus economized adds to the useful work on the piston, the rest passing out in the exhaust gases for recovery.

To insure the maintenance, in a practical and reliable manner, of the temperature conditions that produce this efficiency during the combustion cycle, a departure from the design and construction of the cylinders of normal internal-combustion engines is imperative; they have hitherto been made of cast iron, of a thickness sufficient to resist the working and thermal stresses thrown upon them, including occasional heavy loads caused by preignition of the explosive charge. With these thick walls or liners, the temperature difference between their inner and outer surfaces, which is essential if the surplus heat is to be carried off, can be obtained safely only by the circulation of water at low temperature through the jacket; this is especially the case in cylinders of considerable diameter or capable of high power per swept volume.

The cylinder of a Still engine consists of an inner liner, which is approximately one-third to one-fourth the usual thickness; it is ribbed externally so as to add to its conducting surface and provide suitable passage for the cooling water, and it is reinforced by an outer hoop capable of withstanding the highest pressures to be met with in working. The stresses due, in ordinary practice, to the cold water at the inlet, and the hotter water at the outlet, are suppressed in the Still cylinder, the cooling water being at a controlled and uniform temperature throughout.

STEAM FROM WASTE HEAT.

In gas and oil engines of constant-volume and constant-pressure types the combined losses in radiation—cooling water and exhaust gases—range between 75 per cent and 65 per cent. The highest indicated thermal efficiency claimed under test conditions with a Diesel engine (Mathot) 300 b.h.p., four-stroke at three-quarter load, is 47 per cent (36 per cent brake efficiency). If 4 per cent is allowed for radiation, 49 per cent of the total heat is available for recovery, and if 10 per cent efficiency is assumed for the steam cycle, the brake thermal efficiency of an engine giving this high result would be raised by 10 per cent of $49 = 4.9$; that is, $36 + 4.9 = 41$ per cent; but there is no reason why the steam generated and used under the conditions of the Still system should be limited to so low a figure. Fifteen per cent, according to the author, seems a more reasonable assumption, and even a higher figure may be anticipated, in which case a brake thermal efficiency of 44 per cent should be possible in a complete installation.

The exhaust gases take a subsidiary but important part in the cycle; their usefulness in ordinary combustion engines, in raising steam, is limited to the amount of heat recoverable between the initial temperature of the exhaust and that of, say, 50 degrees F. above the steam temperature, after which the whole volume passes away to atmosphere at a still useful temperature, less a small percentage available for feed-water heating. But in the Still engine the exhaust gases, after raising their quantum of steam, are employed in preheating all the water required for the steam generated in the jacket water and in the generator. Trials at full efficiency over long periods and steady loads, show terminal stack temperatures as low as 150 degrees F.

The piston and cylinder walls, preheated by the combustion stroke, are at a higher temperature than the steam when it is admitted and while it is being expanded; there is, therefore, no loss from condensation, and the steam exhausts at a slight superheat above the normal expansion temperature, a condition which is unattainable in any form of steam engine without direct loss of energy. With an early cut off, it can be expanded economically right out to atmospheric pressure, or below it, and be either recompressed (Stumpf cycle) or exhausted to the condenser. The steam, during expansion, forms an efficient means of cooling the piston.

The Still oil engine starts with the cylinders and pistons preheated. The air charge, from the moment of its entry into the cylinder, picks up heat from the containing walls and continues to do so during at least 70 per cent of the compression stroke, with the result that the temperature necessary for firing with certainty the first injected charge of fuel is reached with a compression pressure 50 per cent less than that required in a Diesel engine.

This fact is far reaching in its importance, for it gives to the designer great elasticity and freedom of application; for a Still heavy-oil engine can be designed for constant pressure or constant volume, or both can be employed in the same engine by correct timing of the fuel injection. It claims for its combustion cycle an efficiency higher than that of the Diesel, less weight and space per horsepower, and for its combined cycle an efficiency not less than 20 per cent higher than any prime mover which uses fuel as its source of heat.

Normal Load—The average m.e.p. from the combustion stroke was 90 pounds per square inch. The steam evaporated by the "waste heat" gave 14 pounds per square inch m.e.p. on every return stroke. This is equivalent to 90 + 28 = 118 pounds per square inch m.e.p. in a normal four-stroke engine.

Overload—By admitting additional steam generated by fuel under the boiler, the steam m.e.p. was raised to 72 pounds per square inch; the total m.e.p. was, therefore, equal to 90 + 144 = 234 pounds per square inch m.e.p. in a normal four-stroke engine.—"Power."

EFFECT OF WATER INJECTION ON GASOLINE ENGINES.

BUREAU OF STANDARDS TESTS SHOW NO POWER GAIN OR DECREASE OF CARBON DEPOSIT EXCEPT IN CASE OF ENGINES WITH DEFECTIVE COOLING SYSTEMS.

The practice of injecting water in conjunction with the fuel is quite common in kerosene engines, the object being to keep down the cylinder temperature under conditions of heavy loading and prevent preignition. In fact, it seems almost impossible to operate an Otto cycle kerosene engine and get satisfactory results without water injection. There also has been considerable experimentation with water injection (or induction) in gasoline engines, not by the manufacturers of the engines, but by makers of fuel conditioners and their customers, who believe that the injection of water will lessen or eliminate the formation of carbon deposit and increase the fuel economy.

In the development of aircraft engines the suggestion was made that if water injection had these effects it should be beneficial in aircraft work. The problem was assigned by the National Advisory Committee for Aeronautics to the Bureau of Standards, and an extended investigation was made. The tests were carried out on a Class B military truck engine,

and also on a Rutenber 6-cylinder, 3 x 5-in. engine, which operated at high jacket temperature. Thus, although the investigation was made at the instigation of the Aircraft Department, the tests were conducted on a truck and an automobile engine, but the results, of course, are of general application.

TWO SERIES OF TESTS MADE.

In a general way, two series of tests were made, one to determine the effect of water injection on the maximum power obtainable from an engine and its fuel economy, and the other to determine its effect upon the carbon deposit on the piston head and cylinder walls.

It may be recalled that the Class B truck engine is a 4-cylinder design with a bore of 4.75 inches and a stroke of 6 inches. The compression ratio is 3.7 and the piston displacement 425 cubic inches. Compression tests made by means of an O-Kill indicator showed an average compression of practically 48 pounds per square inch at 100 R.P.M., the water jacket temperature being 131 degrees Fahr. In the tests this engine was connected up to a 125-H.P. Sprague dynamometer, by means of which the horsepower output was measured.

In the first test the Class B engine was fitted with a Zenith L-6 carbureter. Each series of tests consisted of three runs. After the engine had been brought up to operating temperature the carbureter was adjusted for maximum engine power at full speed, only gasoline being fed into the cylinders. After the engine had been run 5 minutes under these conditions, another run was made with water injection, with the same carbureter and spark setting. Finally, during the third run, also of 5 minutes' duration, the water injection was continued, and the spark was adjusted to give the greatest engine output. Series of tests of this kind were made at speeds of 400, 600, 800, 1000 and 1200 R.P.M. The water was admitted to the manifold at a point 1¼ inches above the throttle valve, and the amount of water fed was read off from a graduated glass cylinder of 1000 cubic centimeter capacity, while the time was taken from a stopwatch. A stopcock in the line between the graduated cylinder and the intake manifold permitted of controlling the water feed.

Three complete series of tests, each covering the whole range of engine speed, were run with the Zenith carbureter. In the fourth test a Stromberg N-3 carbureter, with a 1 5/32-inch choke and a 0.0635-inch bleeder, was substituted for the Zenith, this carbureter permitting of varying the fuel mixture for different speeds. Thus, the effect of water injection could be studied when the fuel mixture was adjusted to be as lean as possible consistent with smooth running, and also when a rich mixture was being fed. In one of the runs a metal plate, with asbestos gasket, was inserted between the intake and exhaust manifold, so as to shut off some of the heat flow from the exhaust to the inlet manifold and permit of determining the effect on the operation due to the lower temperature of the mixture thus obtained.

The final tests with the Class B engine were made under spark-and-throttle conditions simulating road-operating conditions of the motor truck.

AMOUNT OF CARBON DEPOSIT.

One of the chief claims made for water injection in gasoline engines has been that it reduces the amount of carbon deposit and that it will even remove deposits already formed. In order to test the validity of this claim, a Rutenber six-cylinder, 3 x 5-inch engine was mounted on

the test stand and fitted with a fan brake to load it down. Cooling water was circulated by gravity, and in order to form a carbon deposit of some thickness the engine was run for several days with a rich mixture, late ignition, and low jacket temperature. Occasionally oil was injected into the cylinders. At the end of the 6-hour period, all interior portions were covered with a substantial layer of carbon.

The engine was then run for another 6-hour period under wide-open throttle, water being injected into the manifold as in the previous tests. During this run the waterjacket temperature was kept high, the outlet temperature being maintained constant. At the conclusion of this run the cylinder head was removed and the carbon deposit in the combustion chamber examined, but no noticeable effect was found. Other similar tests were made, the rate of water injection and the temperature of the jacket water being varied. The rate of water feed varied from 2.4 pints to 7.05 pints per hour. With the higher rates of water feed the engine power output was noticeably decreased.

The results arrived at have been summarized by the experts of the Bureau of Standards somewhat as follows:

No appreciable effect is produced upon the power, fuel economy and general operation of a gasoline engine by the injection of water into the cylinders at rates varying from 0.03 to 0.44 pound per brake horsepower-hour. When water is injected at a higher rate than 0.44 pound per brake horsepower-hour there is an appreciable decrease in the power output, fuel economy and smoothness of operation. It is quite probable that in a badly carbonized engine, or an engine of defective design, in which there are hot spots that cause preignition, the injection of the water results in an increase of power. In an engine operating at high water-jacket temperature the injection of water in amounts between 2 and 8 pounds per hour produces a softening and slight reduction of carbon, this reduction not exceeding 25 per cent and being most noticeable on the piston heads and valves. However, water injection at the maximum rate also causes a considerable reduction of power.—"Automotive Industries."

ONE THOUSAND DOLLARS WILL BE PAID FOR A SINGLE WORD.

WORLD TRADE CLUB OFFERS PRIZE FOR BEST NAME FOR "BRIT-AMS."

Can you create the one word which will best denote the United States and all parts of Britannia? If so, you will be paid at the rate of $1,000 a word. The World Trade Club of San Francisco has offered $1,000 to the person who suggests the word which, in the judgment of the club's Metric Campaign Committee, is best adapted to world-wide use.

The competition is open to all humankind. The money will be paid to the winner at noon on 15th May, 1920, by a committee appointed by President W. H. Hammer of the World Trade Club.

"Brit-Am," "Ambria," "Ambrittica," "Br-Am," "Sam-Bull" are some words thus far suggested. New names are constantly coming. The World Trade Club is offering this award because in carrying on its present campaign for the adoption of metric units by all English-speaking people—the United States, the British Isles, Canada, Australia, New Zealand, Tasmania, United South Africa and so on—it was hampered by the lack of a single short word which would express all these.

The metric units of weight and measure are now used by all the world except "Brit-Am" or "Ambrittica" or "Sam-Bull."

SOME FACTS ABOUT MONEL METAL.

By Hugh R. Williams.*

Conditions surrounding the use of high-pressure steam, particularly when superheated, are different from those met with in low or medium pressure saturated steam practice. High-pressure strains, greatly elevated temperatures and intensified erosive action, all have to be contended with, making necessary the employment of much equipment of a character different from that suitable for less severe conditions. Particularly is this so of the metals employed.

The requisites for a metal to withstand the high pressures, the total heat—possibly as high as 800 degrees F., or even higher—and the erosive action of high-pressure superheated steam are: (1) High tensile strength at all temperatures; (2) low heat conductivity; (3) high modulus of elasticity; (4) a coefficient of expansion permitting its use in combination with other essential metals; (5) capacity to resist the erosive action of the steam. If, in addition, the metal might be of a non-corroding nature, markedly resisting oxidation, it would be the ideal metal for superheated steam service.

Valve manufacturers, upon whom devolved the important necessity of producing devices to control and regulate the flow of the more powerful operating medium, were among the first to appreciate the inadequacy of their former product to handle successfully high-pressure superheated steam. Cast-steel valves were necessary to replace the extra-heavy cast-iron ones suitable for steam pressures up to 250 pounds to withstand the increased steam pressures and the much more marked elevations in temperature without unduly adding to the weight of the valves. These valves, as in the case of iron-body valves, required seat rings, valve disks and other fittings and trim made of durable and non-corroding metal to assure tight closure in operation. The fittings for iron valves, usually of brass or bronze composition, are not suitable for cast-steel valve service, for the coefficient of expansion of cast steel is nearly double that of cast iron, brass or the bronzes used for valve fittings. The difference in the expansion of the valve-body metal and the valve fittings under the range of temperature encountered in high-pressure superheated-steam service would be such as to prohibit tight closure and produce serious deformation of valve seats, etc., at unusual temperatures. The difficulty was overcome by making the fittings for cast-steel valves out of monel metal, a natural alloy of individual characteristics, possessing a coefficient of expansion practically identical to that of steel. This monel metal is non-corrodible, strong as steel, tough and ductile. It takes and retains a high finish, is a better resistant to acid and alkaline corrosion than any of the common metals and is practically impervious to oxidation. It can be machined, forged, soldered and welded, both electrically and by the oxyacetylene process.

This metal is a natural product of the distinctive nickel and copper ores mined in the Sudbury district, Ontario, Canada. The ore is a basic igneous rock carrying sulphides of nickel and copper with pyrrhotite (magnetic pyrites) as constituents—the sulphides more or less segregated—and is smelted to matte form by a special roasting process that drives off the sulphur content without disturbing the balance of the main metal ingredients, copper and nickel. The process practically eliminates the sulphur content, and the matte, refined to get rid of impurities, produces a metal of unusual uniformity of composition—nickel, 67 per cent; copper, 28 per cent; and other elements, chiefly iron from the

*The International Nickel Co.

original ore and manganese, silicon and carbon introduced during the process of refining, 5 per cent.

The physical characteristics of the metal—it was not until 1906 that a practical method of producing monel metal was developed—are decidedly distinctive and individual. They are not and cannot, so far as known, be possessed in any like measure by synthetic mixtures of similar ingredients, for no mechanical process, so far as known, can produce the intimate combination resulting from centuries of geological formature.

The requisites for a metal to withstand the severe conditions of high-pressure superheated-steam service are apparently all possessed by monel metal, as evidenced by its physical properties. The one question remaining in doubt, or not conclusively established by the physical properties of the metal under normal conditions, is its ability to withstand effectively the universally weakening effect of high temperatures.

However, a series of comprehensive and exhaustive tests conducted by some of the leading valve manufacturers showed that in this respect monel metal is quite unique among metals in having its strength less influenced by elevated temperatures than any other known metal. Under

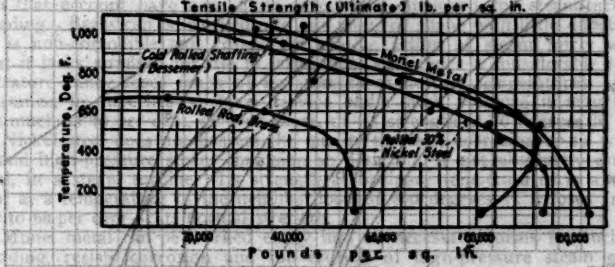


FIG. 1. BEHAVIOR OF MONEL AND NICKEL STEEL.

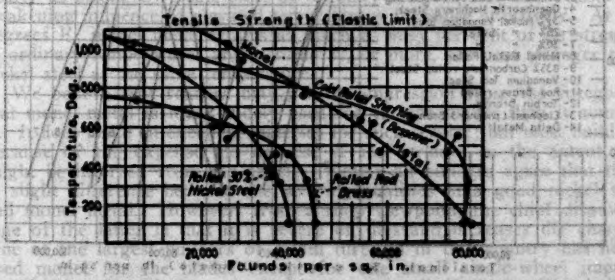


FIG. 2. ELASTIC LIMIT AT HIGH TEMPERATURES.

any heat up to 1,000 degrees F., its ultimate tensile strength in rolled form is considerably greater than that of any other metal ordinarily furnished in the form of rods. It is considerably stronger than 30 per cent nickel steel at all temperatures and at high, as well as normal, temperatures is stronger than cold-rolled shafting bessemer. Even at

500 degrees F., at about which temperature cold-rolled shafting possesses its maximum strength, monel-metal rods are slightly the stronger. At the elastic limits of the various metal rods, monel metal possesses greater tensile strength than do rods of any other metal at temperatures exceeding that of about 800 degrees F. Below this temperature, bessemer cold-rolled shafting is somewhat the stronger at the elastic limits of the respective metals, but monel metal resists the action of corrosion and oxidation far more effectively.

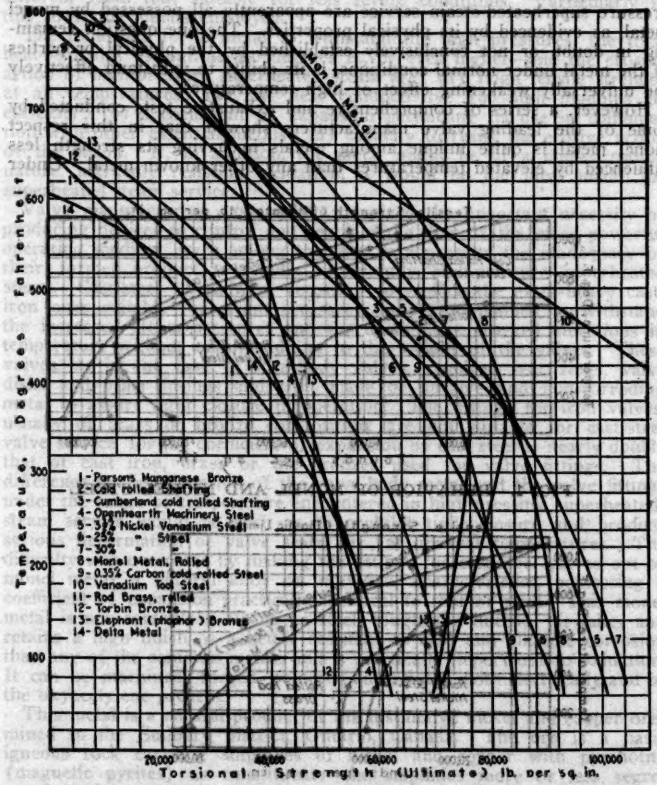


FIG. 3. BEHAVIOR OF MONEL AND OTHER METALS AT HIGH TEMPERATURES

Under torsion monel-metal rods are even stronger than bars of vanadium tool steel at temperatures in excess of 600 degrees F. and at all temperatures monel-metal rods are stronger than rods of nickel steel, any of the bronzes, cold-rolled shafting, machinery steel, delta metal, etc.

In the form of rods the metal is also of quite unusual importance in the power house. Monel-metal pump and piston rods, in particular, are

highly economical, for they are more durable than steel or bronze rods and effect a substantial saving in power consumption and the use of packing. They do not score or pit and acquire a smooth, glassy surface in service that reduces friction to a minimum, avoids wear on the packing and eliminates to a great extent the leakage evil.

For parts of valves, in fabricated forms as bolts, nuts, screws, etc., for severe service and for use in connection with cast-steel mechanisms, monel-metal rods find many uses.

Another use of monel-metal rods, in which service the metal has also assisted in power-plant practice, is in connection with steam-turbine construction. The successful development of the steam turbine has been dependent to a considerable extent upon employing a suitable metal for the blades. A metal is required that will stand up well under the erosive action of high-pressure steam, resist corrosion, will retain strength at elevated temperatures and which can be worked easily into the required shapes. The first three requirements are essential and the last a matter of practical consideration.

There are three classes of metals—brasses, nickel steel and monel metal—that meet each of the four requirements to a certain extent and on that account have been quite extensively employed for steam-turbine blading. Brass can be worked into any required shape with little difficulty, it is non-corrodible and resists the erosive action of steam fairly well, but it lacks strength for use in large units and under a considerable temperature range loses much of its strength at normal temperatures. For instance, in superheated-steam service under high pressure it may lose as much as 40 per cent, or even more, of its strength at 70 degrees F.

Nickel steel does not possess the quality to resist corrosion or to withstand high-pressure steam corrosion so desirable, if not absolutely essential, in a steam turbine. Its strength at ordinary temperatures is ample, but at a temperature in the neighborhood of 800 degrees F. it loses from 50 to 60 per cent of its normal strength.

Monel metal can be worked easily into all necessary forms for turbine blading, resists corrosion and the erosion of high-pressure steam even better than does brass, on account of its high nickel content, is very nearly as strong as nickel steel at ordinary temperatures and resists the weakening influence of elevated temperatures far more effectively. At 800 degrees F., monel metal retains as much as 66⅔ per cent of its strength at ordinary temperatures and is some 30, or more, per cent stronger than nickel steel at the same temperature.

[We believe that readers may get the impression from the foregoing, that monel metal is more widely used for turbine blades than it actually is. It does make an excellent material for such service; but most builders, because of the expense, do not use it for turbines to the extent that might be inferred from the article. Nearly all builders agree that there is slight difference between the wearing qualities of a good nickel steel and monel metal. However, from a shop viewpoint, the chief disadvantage of the latter is that it is severe on dies and increases die charges. One of the largest builders of steam turbines in this country has never used monel for the blades except for one small single-wheel impulse machine in which the steam velocities are exceedingly high. This builder doubts that monel is as good for high-speed blades as pure nickel, which is now available. Great physical strength in the high-pressure blading in modern turbines is not vital. For the sake of efficiency all such blading, whether impulse or reaction, should operate at slow speeds, which result in low mechanical stresses. For the exhaust end blading where these stresses are high low-carbon, nickel, electric-furnace steel is widely used.—Editor.]

TABLE OF PHYSICAL PROPERTIES.

Melting point of monel metal, degrees	1,360 C. (2,480 F.)
Specific gravity (cast)	8.87
Weight per cubic inch (cast), pound	0.319
Weight per cubic inch (rolled), pound	0.323
Coefficient of expansion (20 deg. C.—100 deg. C.)	0.00001375 per deg. C.
Electrical resistivity, 256 ohms per mil-foot (temp. coefficient),	0.0011 per deg. F.
Electrical conductivity	4 per cent (copper 100 per cent)
Heat conductivity	1/15 that of copper
Shrinkage	¼ in. per foot
Hardness, cast material	20-23 (Shore scleroscope)
Hardness, hot-rolled rods	27 (average shore scleroscope)
Hardness, hot-rolled rods	162 (average Brinell)
Modulus of elasticity	22,000,000-23,000,000

TESTS ON RODS.

Tensile.

Average representative tests of each of the three divisions as given:

	Yield Point, Lb. per Sq. In.	Ultimate Tensile Strength, Lb. per Sq. In.	Per Cent. Elongation in 2 In.
Up to 1 in.	63,126	94,562	40
1 1/16 in. to and including 1 11/16 in.	61,963	93,104	39
1¾ in. to and including 2 7/16 in.	50,115	87,678	42
2½ in. to and including 3½ in.	43,805	85,282	44
Over 3½ in.	47,335	84,763	43
Rectangles	56,353	85,562	42
Hexagons	60,736	87,781	40

Torsional (Average).

Shearing stress—pound per square inch on remotest fibres:

At elastic limit	31,796
At ultimate load	79,053

Compression.

Elastic limit ..... 25,500 to 32,000 lb. per sq. in.

TEST ON CASTINGS.

Tensile.

Average of 172 heats tested for Isthmian Canal Commission:

Yield point	37,093 lb. per sq. in.
Tensile strength	72,281 lb. per sq. in.
Elongation in 2 inches, per cent	34
Reduction of area, per cent	32

Compression.

Elastic limit ..... 12,000 to 25,500 lb. per sq. in.

—"Power."

TESTING WATERTUBE BOILERS.

The writer has recently had under his charge the testing of some eighty or ninety new watertube boilers, and the preparing of same for steaming conditions. As the method adopted has been very successful, and may also be applied to some other classes of watertube boilers, these notes may be of interest.

First, a general idea of the boilers under consideration will be given, and then the three following items discussed:

1. Character of test required.
2. Preparing for and carrying out test.
3. Preparing for steam.

The boilers referred to above were of the Yarrow type: Steam drum, 50 inches diameter by 12 feet long; water drums, 30 inches by 12 feet long; number of tubes, about 3,500 of 1-inch diameter, except the three inner rows on each side, which are 1¼ inches in diameter; average length, about 8 feet.

The steam drum carries four safety valves bolted to pads and riveted on the shells. The front head carries the main stop valve, surface blow, two water gages, three try cocks and the auxiliary feed valve. The internal auxiliary feed pipe, scum pipe and steam-dryer pipe are fitted in the drum. The manhole is 16 inches by 12 inches.

The water drums (front heads) carry the main feed valves, and one drum is fitted with a salinometer cock. Each drum has an internal feed pipe arranged in a casing so as to cause a forced circulation. Blow-down valves are fitted to the shell of each drum. The manholes are 16 inches by 12 inches. Each boiler was capable of giving 7,000 horsepower, burning oil in a closed fire-room.

CHARACTER OF TEST REQUIRED.

The character of the test required is as follows: Drums and tubes are to be tested to 400 pounds cold water pressure for one hour. The boiler, complete with all mountings, to be tested on board to 330 pounds cold water pressure for a period of six hours, a loss of eight pounds being the limit allowed in this time.

It will be readily admitted that such a test is severe and calls for careful preparation.

PREPARING FOR AND CARRYING OUT TEST.

As they come from the shop the boilers are usually in a very dirty condition; oil and grease from the tube expanders, chips of metal, scale, rivet heads, etc., are sure to be found in plenty. The oil need not trouble us at this stage, but all particles of metal, or anything liable to damage the valves, must be thoroughly blown out with an air hose; also each individual tube should be blown in order to ensure that it is clear. The boiler valves, though new, should all be taken apart, cleaned, and given a rub with finest emery to ensure a perfect seat. It is impossible to lay too much stress on the fact that this work must be faultless; a drop, however slight, is enough to spoil a perfect test.

After all the valves have been attended to, the safety valves may be gagged, the manhole doors carefully put on, air cock opened and the boiler filled slowly. For obtaining the best results all the air should be driven out, and this is sometimes a difficult matter. The air cock is usually fitted to the top of the drum, but a certain amount of air is trapped in the safety valves and in the main stop if this rises much

above the level of the top of the drum. However, the amount trapped is small, and it is preferable to allow it to remain rather than to open the valve, as there is sure to be some little particle of grit in the water that may lodge on the seat and necessitate regrinding.

Having the boiler full, we may proceed to pump up by the hand pump to about 100 pounds. At this pressure it is well to make a thorough examination of the boiler, looking to all seams, rivets, mountings and tubes. Any leaky tubes can be easily detected by a long lighted taper passed between the rows. Assuming all is well, the pressure may be increased to 200 pounds, and later to 250 pounds, a good examination being made at each pressure. The manhole doors will probably require a little tightening up by this time.

If any fittings should be found porous they must be dealt with as experience dictates. A very small leak may be stopped by peening with a hammer or by a calking tool, care being taken to relieve the pressure first. If a casting is spongy it should be removed and a new one fitted in place. Valves not exposed to steam, as, for instance, the main feeds, may be tinned, if necessary.

Let us now assume that all is satisfactory and that the pressure on the boiler has been raised to 330 pounds without any leaks. We can relieve the pressure and prepare the boiler room for the final test.

All gages to be used should be calibrated and large gages should be used, so that a drop of even half a pound may be noted. Boiler room hatches should be closed or covered with canvas, and all openings in bulkheads plugged up, in order that the boiler may not be subjected to any draft. Stacks must also be covered, and all openings to the furnaces closed.

When this is done, and the necessary thermometers, etc., are in place, the inspector may be called, the boilers pumped up to the full pressure, and the hand pump locked or disconnected.

Readings should be taken every half hour. If it is desired to gage any part of the boiler while under test, suitable arrangements must be made beforehand.

The writer took some measurements of the boilers both before the pressure was applied, and while it was on, with the following results: After a 400-pound test on the shell and tubes (all openings for fittings being blanked) the part faced for the main stop showed a permanent distortion of thirty-seven thousandths, and the faces for water gage fittings as much as twenty-five thousandths. All these faces had to be scraped up again before fitting the mountings. Before applying the 330-pound test with mountings in place, measurements were taken between port and the starboard water gage fittings (top) and found to be 24 inches. While the pressure was on, this showed 24¼ inches. The fittings were bolted to extensions on the head about 8 inches long. A tram was also made from the boiler shell to the top of the main stop spindle, and under this pressure showed a difference of ⅛ inch. The head was ¾ inch thick.

PREPARING FOR STEAM.

After the test has been passed, we may proceed to clean the boilers, as follows: Having emptied them and removed the bottom manhole doors, we put into each bottom drum 25 pounds of soda, 6 pounds of lye and 5 gallons of coal oil. Replace the manholes and put in enough water to fill the bottom drums. Then connect a temporary steam pipe to the bottom blows and admit steam carefully at about 40 pounds pressure. The steam will condense, and, in time, bring the water to the boiling point.

When the pressure on the boiler is approaching that of the incoming steam, the surface blow may be slightly opened to maintain a pressure of 25 or 30 pounds. The condensation of steam will soon fill the boiler to the level of the scum pan, and all oil and grease will be removed in this manner.

Boiling is continued about 70 hours. At the end of this time, the boilers may be emptied and allowed to cool and then the manual part of the cleaning will commence. The tools required are few and simple: Wire hand brushes, tube brushes, wire cables fitted with sockets into which the tube brushes are screwed, scrapers, and a bale of rags, are all that we require.

First the internal pipes are removed and the top drum brushed down thoroughly with the wire brushes, care being taken to clean well around the tube ends. Sometimes there is a little mill scale found on the heads, especially around the flange, and this can be removed with scrapers. It is not well to try to chip it, as the head must be left as smooth as possible.

When this is finished, the tubes may be started. The wire brushes should be wrapped with rags, as this leaves the tubes in a fine polished condition, whereas a wire brush alone makes them look streaky. The brushes will only clean the parallel part of the tubes, and the bell-mouth must be "poked" by means of a stick wrapped with rags.

After this is done, the drum and tubes may be blown out with the air hose, and then the bottom ends of the tubes "poked" in a similar manner and the bottom drums wire-brushed, and, if necessary, washed with coal oil.

As soon as the bottom drums are finished and attention has been given to all the small outlets for water gage fittings, etc., which are easily choked up, the boiler may be inspected by the chief engineer of the ship, who should, in the case of straight-tube boilers, "sight" every tube from the top drum, while his assistant holds a light at the bottom. If the inspection is satisfactory, the internal pipes may be cleaned and replaced, and the boiler filled to the working level with distilled water.

Should the boilers not be required for any considerable time, it is better to fill them right up to the air cock with slightly alkaline water, or they may be left dry and a tray of burning charcoal introduced into each bottom drum and the boiler closed entirely.—"International Marine Engineering."

HEAT-TREATMENT OF LOW-CARBON STEEL.*

By W. M. Wilkie.

In annealing, the operation consists in (1) slowly raising the steel to its upper critical temperature; (2) holding it or soaking it at this temperature for a certain time, depending on the size of piece being treated and the condition of previous treatment; and (3) cooling from annealing to atmospheric temperature.

Theoretically, as the steel is heated to the lower critical point, the usual transformation from the phases of softened steel to austenite is commenced, and continues through the critical range, so that when the upper critical point is reached the steel should be all austenite. As a result of this transformation all pre-existing structures, no matter how coarse, are obliterated, and the mass assumes an amorphous structure, providing sufficient time has been taken in heating to permit these changes to occur.

*Abstracted from the "Journal of the American Society of Mechanical Engineers."

Further, if the temperature is carried above the upper critical point the tendency is for this amorphous structure to become crystalline again. Hence, in annealing steel its temperature should theoretically be raised to the upper critical point only, but practically there are conditions that modify this. For example, in cast steels we find that temperatures considerably higher (as much as 180 degrees F. above the theoretical temperatures), combined with long soaking, are required to break up the coarse-grained structure.

TABLE I.—ANNEALING TEMPERATURES FOR STEEL.

Range of Carbon Content, per cent.	Range of Annealing Temperatures, F.
Less than 0.12	1607 to 1697
0.12 to 0.25	1544 " 1598
0.30 " 0.49	1499 " 1544
0.50 " 1.00	1454 " 1499

Mechanical work on steel seems to have the same effect—namely, it breaks up this intercrystalline film, and as a result we find that the more a piece of steel has been worked, the closer the annealing temperatures can be kept to the upper critical point, while the nearer the steel is to the unworked or cast condition the higher the temperatures must be. The ranges of temperatures given in Table I have been recommended by the Committee on Heat-treatment of the American Society for Testing Materials.

The time of soaking depends largely upon the size of the object being annealed, but sufficient time should be given to permit the object to be heated throughout to the annealing temperature and allow the internal changes to occur. Pieces 12 inches thick require about one hour.

The rate of cooling after annealing is controlled by the product required. If a maximum softness and ductility is desired, for instance, for easy machining, we cool as slowly as possible by either burying the article in a bed of insulating material or allowing it to cool in the furnace. If, however, we wish to retain a certain amount of hardness and strength we must cool faster, as in air, or, if a low-carbon steel, in water; but to do so we must sacrifice a certain amount of ductility and softness. As a general rule, the lower the carbon the more rapid may be the cooling. For example—

1. Steels with carbon content below 0.15 per cent can be quenched in water and remain ductile, and at the same time have maximum hardness and strength.

2. Steels with carbon content below 0.30 per cent can be quenched in oil with results similar to 0.15 per cent carbon quenched in water.

3. Steels with carbon above 0.30 per cent cannot be cooled so rapidly without destroying the ductility of the steel, and so must be cooled in the furnace, or in the air when extreme softness is not required.

The size of objects must also be considered along with the product desired. Other things being equal, the larger the object the more quickly must it be cooled, as long as the cooling is not so rapid as to set up strains.

As an example of the effect of rate of cooling on the strength of steel, we have a system of strengthening steels on high-explosive shells known as the Sandberg air-cooling method. By this method air at pressures ranging from 6 ounces to 15 ounces, usually around 10 ounces, is either passed around the shell-forging or forced to impinge on the revolving shell in such a way that a shell which would normally cool in 30 minutes

or more in the open air, is cooled in 6 to 8 minutes. As a result the ultimate strength is raised with an increase in the elastic ratio, but with little variation in the ductility of the steel. This process is really an intermediate treatment between annealing and the regular hardening of steel, due to the formation of sorbite. Another way to get this sorbitic steel is first to quench steel from the upper critical range, thus retaining its fine-grained structure, but leaving the steel very hard and without ductility. The steel is now reheated close to but below the lower critical range—say, from 932 degrees to 1202 degrees F., when it loses its hardness and becomes ductile. The reason for this is that the steel has been changed from martensite to sorbite. This is really a hardening and tempering treatment, but is referred to here because it is sometimes called a double annealing treatment.

The hardening temperatures in Table II are given by E. F. Houghton and Co.

TABLE II.—RELATION OF HARDENING TEMPERATURE TO CARBON CONTENT.

Carbon Content, per cent.	Hardening Temperature, F.
Up to 0.20	1600 to 1650
0.20 to 0.35	1550 " 1600
0.35 " 0.50	1500 " 1550
0.50 " 0.70	1450 " 1500
0.70 " 0.90	1400 " 1450
0.90 or over	1350 " 1400

Steel is most commonly quenched in oil or water. In either case care must be taken, especially with high-carbon steels, to prevent cracking as the result of strains set up by too rapid cooling. If oil or water is used, the object should be withdrawn from the bath before its temperature has fallen below 212 degrees F., and the drawing or tempering treatment should follow immediately.

If a piece of polished steel is heated in an ordinary furnace a thin film of oxides will form on its surface. The colors of this film change with temperature, and so in tempering they are generally used as an indication of the temperature of the steel. The steel should have at least one polished face so that this film may be seen.

An alternative method to the determination of temper by color is to temper by heating in an oil or salt bath. Oilbaths can be used up to temperatures of 500 degrees F.; above this, fused-salt baths are required. The article to be tempered is put into the bath, brought up to and held at the required temperature for a certain length of time, and then cooled, either rapidly or slowly. This takes longer than the color method, but with low temperatures the results are more satisfactory, because the temperature of the bath can be controlled with a pyrometer. The tempering temperatures given in Table III are taken from a handbook issued by the Midvale Steel Company.

TABLE III.—TEMPERING TEMPERATURES FOR STEELS.

Temperature for 1 Hour F.	Color.	Temperature for 8 mins. F.	Uses.
370	Faint yellow	460	Scrapers, brass-turning tools, reamers, taps, milling-cutters, saw-teeth.
390	Light straw	510	Twist-drills, lathe-tools, planer-tools, finishing-tools.

410	Dark straw	560	Stone-tools, hammer-faces, chisels for hard work, boring-cutters.
430	Brown	610	Trephining tools, stamps.
450	Purple	640	Cold-chisels for ordinary work, carpenters' tools, picks, cold-punches, shear-blades, slicing-tools, slotter-tools.
490	Dark blue	660	Hot-chisels, tools for hot work, springs.
510	Light blue	710	Springs, screw-drivers.

Two sets of temperatures are shown, one being specified for a time interval of 8 minutes and the other for 1 hour. For the finest work the longer time is preferable, while for ordinary rough work 8 minutes is sufficient after the steel has reached the specified temperature. The rate of cooling after tempering seems to be immaterial, and the piece can be cooled at any rate, providing that in large pieces it is sufficiently slow to prevent strains.

How are we to know if we have given a piece of steel the very best possible treatment? The best method is by microscopic examination of polished and etched sections, but this requires a certain expense for laboratory equipment and upkeep, which may prevent an ordinary commercial plant from attempting such a refinement. However, I would certainly recommend any firm that has any large amount of heat-treatment to do to install such an equipment, which can be purchased for 250 to 500 dollars. Its intelligent use will save its cost in a short time.

The other method is by examination of fractures of small test-bars. Steel heated to correct temperatures will show the finest possible grain, whereas underheated steel has not had its grain structure refined sufficiently, and so will not be at its best. On the other hand, overheated steel will have a coarser structure, depending on the extent of overheating.

To determine the proper quenching temperature of any particular grade of steel it is only necessary to heat pieces to various temperatures not more than 36 degrees F. apart, quench in water, break them, and examine the fractures. The temperature producing the finest grain should be used for annealing and hardening.

Similarly, to determine tempering temperatures, several pieces should be hardened, then tempered to various degrees and cooled in air. Samples, say six, reheated to temperatures varying by 180 degrees, from 570 degrees to 1470 degrees F., will show a considerable range of properties, and the drawing temperature of the piece giving the desired results can be used.

The following precautions should be observed in the heat-treatment of steel:

1. Do not put a cold piece of steel into a highly heated furnace. Either reheat it or put it into a cold furnace and allow it to heat with the furnace. This precaution is especially applicable in cold weather. Remember also that the changes occurring in the critical range are not instantaneous. The steel must be given time to change. It does not pay to rush the heating. Raise the temperature slowly.

2. Allow the piece to soak at the quenching temperature until it is uniformly heated throughout, the length of time depending on the size of the piece and the rate of heating.

3. Do not allow the piece to be directly on the hearth of the furnace, but have it supported at a sufficient height for free circulation of gases on all sides. Long pieces should have sufficient support to prevent sagging.

4. Never allow a piece, especially if it has points or sharp corners, to come in contact with flame.

5. In quenching, immerse the piece with the axis vertical. This will prevent excessive warping or cracks due to unequal contraction in cooling.

6. Care should be taken that no sharp grooves, corners, or seams, which may develop into cracks, are left on pieces to be quenched.

7. In drawing the temper of a large piece in a furnace, never put it in a furnace hotter than the drawing temperature, nor allow the furnace to exceed the required temperature, otherwise the steel will be softer than required.

8. In drawing large pieces, soak a sufficient time at the desired drawing temperature to allow the heat to affect the center of the piece.

9. In annealing and quenching, never depend on the eye to judge the temperature; use a pyrometer.—"Mechanical World."

THE IMPORTANCE OF ENGINEERING TO THE NAVY.

EXTRACTS FROM AN ADDRESS DELIVERED BY HON. JOSEPHUS DANIELS, SECRETARY OF THE NAVY, AT THE OPENING EXERCISES OF THE POST GRADUATE SCHOOL, AT ANNAPOLIS, THURSDAY NIGHT, JUNE 12TH.

Engineering has come to be the chief profession in America, for everything that moves depends upon the genius, knowledge and skill of men who are as much at home in overalls as in dinner coats, who love to make the wheels go round, and who understand that motive power is the center of world progress and world prosperity.

There are four callings that add most to the sum of human wealth—the farmer, the miner, the artisan and the engineer. The last is an old profession, as the water system and baths and roads of ancient Rome testify, but its expansion to cover all fields has been the outstanding creator of wealth of our day along new lines. It makes land, the one thing it was said man could not create. It carried the water power of Niagaras, great and small, to distant centers. It increases the fruit and grain of the soil and multiplies the product of the artisan and gives new value to mineral deposits. It makes possible girdling the globe on the sea, under the sea and in the air. And yet, because it works in the bowels of the earth and in the lowest decks of the ship and in places away from the crowd, the recognition it deserves has not hitherto been given to these creators of wealth.

When one takes a voyage across the ocean (and more Americans have crossed this year than in the preceding hundred years) he understands as never before what he owes to the men in the fire-rooms, far below the water's edge, who in a temperature that compels return to Adam's style of garment, make possible safe transportation in comfort. A visit from the bridge to the engine-rooms is an education in the achievement of the engineer, for in our modern use of the term a naval constructor as well as the men who design and build and operate the great engines in a modern ship is an engineer. The captain presses a button, and lo, the ship reduces or increases its speed, and as you see this modern miracle you almost imagine it is automatic. But you leave the bridge and go below if you can squeeze into narrow compartments where men spend their lives and climb down narrow iron steps. The temperature rises and by the time you reach the fire-room you wish you had left your coat and vest and shirt on deck, for you find the men working in a heat they cannot endure longer than four hours. As you stand there, streaming with perspiration, you take off your hats in honor to the men who in grime and heat are carrying you to your destination.

When you are again on deck, enjoying the cool breeze or partaking of a good meal, you cannot forget that below decks toiling in the grim unlighted places are the engineering force of the ship. No man in the world lives with the comforts of life without obligation to other men who sweat and strive to give him the comforts and he seldom stops to ask to whom he is indebted.

I never felt so fully the obligation to these men who keep the engines going as upon a recent trip across on the *Leviathan* and back on the *Mt. Vernon*. Heaving coal into the furnace is not my long suit, but I tried a turn at it along with the boys, and was glad it was only minutes instead of hours that held me to the hard task with the thermometer at 135 degrees. Thanks to American engineering skill, we run both these former German ships on less coal than when the much vaunted German efficients operated them, and we give better accommodations and are arranging for otherwise improving conditions aboard ship for these essential men. There is no more inspiring story of the war than the heroism of the men on the *Mt. Vernon* when she was torpedoed. This characterized all the men of every rating from Capt. Dismukes, a skilled engineer officer, to the youngest recruit. It was collective heroism. But it was conspicuously true in the fire-room where the torpedo struck and where thirty-seven men were killed at the post of duty in the darkness without a moment's warning. Immediately after the torpedo struck there was not only a maelstrom of inrushing water, but the air was filled with soot and cinders and the shovels in the fire-room were thrown in various directions. The lights were put out and the fire-rooms were in darkness, but every man stuck to his job, the reserve crew hastened to lend assistance, climbing into what appeared to be a regular death-trap, and when it almost appeared to every one in those fire-rooms that the ship was sinking. And yet by collective heroism, under plans already worked out by the captain and officers, mainly due to the engineering force, the miracle of that ship returning to port under its own power was witnessed to the glory of the American Navy. Individual heroism entitles Chief Water Tender O'Connor and Patrick Fitzgerald to rank with immortals; Hoke Smith to a high place; distinction to Commander Guttormsen, chief engineer, and the whole engineering force; all honor Executive Officer Commander Staton and Lieut. Doyle, with the other officers and men who made up Capt. Dismukes' minute-men.

Before this opportunity to display heroism, engineering skill had made possible in an incredibly short time the repair of the destruction the German had wrought before leaving this and other ships—one of the most subtle achievements of the war. But it was only a signal instance of engineering skill and illustrative of what was done in designing and building submarine chasers, mine-layers, Eagles, destroyers and other craft the character of the war demanded. The flight of the NC across the Atlantic was due to engineering skill and vision, as was the adoption of the electric drive on dreadnaughts.

We have made progress in naval engineering, but what has been done is but an earnest of what the younger men in their day will achieve unless we are to mark time and surrender leadership to others. In the immediate expansion of the merchant marine and in the larger ships the Navy is building, there will be not only ample opportunity, but compulsion for greater study of engineering progress afloat than in any previous decade. With automobiles and air-craft making new records on the land and in the air, engineering skill must be applied to faster ships and better working conditions on naval craft and on merchant vessels.

There must be specialization, but in addition there must be more general study of engineering problems by all the officers in the Navy. It

ought to be impossible for any naval officers to reach the grade of captain who had not had an actual tour of duty as engineer officer as well to have studied engineering in the Academy and particularly in this post-graduate school.

Although it is now a generally recognized fact, yet it is well to emphasize that the policy which was established some years ago of requiring all officers of the Navy to be educated as engineers and line officers and to require all officers to be capable of performing engineering duties has done more to improve the general efficiency of the Navy than any other one thing.

This is due to the fact that such a large part of every officer's duties involves handling or operating some kind of an engine or machine which is used for a fighting purpose in ships of the Navy and it is of course evident that the best results can only be obtained when the officers handling these machines have a thorough understanding of their mechanics and their methods of operation.

It is frequently argued that the field of engineering is so vast that no one person can properly master it and in addition be a master of the other branches of the Naval profession. It is true that the field of engineers is a vast one because in our ships of war we utilize machines for military purposes which involves nearly all the branches of this wonderful science. We have all the various types of steam engines, and, we might well say, *gun engines*, but the point which is frequently overlooked, is, that there is a vast difference between the knowledge required to operate a machine and to build one. One does not need to know how to build an automobile engine in order that he may operate it in driving the automobile, although he can operate his automobile with better success and efficiency if he has some knowledge of the principles which underlie the construction of the engine, and it is due to this fact that it has been demonstrated that the officers of the Navy as a whole, can be trained to operate the engines and to do the general engineering duties, although it may not be practicable to train all officers to be expert designers of the engines. A knowledge of one kind of machine also greatly assists one in understanding another kind of machine and if an officer has experience in operating the steam and electrical engines of a ship, he is better fitted to operate the gun engines of the ship and to operate the ship as a whole, which is really one large machine. The operation of the engineering departments of our ship also involves a large amount of executive work, due to the large number of men required in the engineering departments and the experience which officers doing engineering duty have of this executive nature also fits them for the other executive duties of the ship, including that of the commanding officer.

An officer's entire service in the Navy is one of continuous training and should be one of progressive development, looking to the day when he is placed in command of the largest type of fighting ship, and if an officer has served in each of the various departments of a ship's organization, particularly in the engineering department, he is thereby much more capable to exercise the high office of command and is thereby better fitted to train and prepare his ship as a whole to meet the acid test of the day of battle.

Recognizing, however, that there is a particular need for a small number of officers who have a more expert knowledge than can be required of all officers of the various types of the engines and machines, including the guns, which are placed in our fighting ships, we have established this special school, called the Post Graduate Department of the Naval Academy, to give a comparatively small number of officers of special qualifications this opportunity for specialization. It is for the

purpose of this special training as experts that you gentlemen are assigned to this school. The number of officers needed for this purpose, however, is not large and it is not deemed desirable now for a large and separately organized corps to perform these duties, although there must be a few officers who will be especially designated for the service as expert engineers throughout the entire length of their service in the Navy.

The time spent in gaining this expert knowledge is not lost, but is of the greater value, even though an officer may not be designated for this special duty throughout his career. On the other hand, he will be much better fitted to perform any of the various duties which he may have, due to this special training, for engineering proficiency is the most needed of all efficiency in naval officers.

I urge you to use every endeavor to utilize this opportunity to develop your expert knowledge, with the idea principally in mind, that you will thereby be a more efficient officer and of greater value to the Navy and to your country for having taken this course, even though you may not be assigned the duties of an expert in any particular work, because after all, the highest ambition is to be a hundred per cent good, all-around officer of the Navy, ready to perform any duty which may be assigned to you.

Due to various reasons, it has appeared to me, sufficient importance is not given by the officers of the Navy, as a whole, to the value of engineering duties, and I think it would be well if all young officers at a suitable time shortly after completion of their course at the Naval Academy were required to perform engineering duties in a ship for a certain continuous and definite time, as it is my opinion that this experience would serve as the best foundation for all the duties which the young officer would be called upon to perform in his future service.

It should be realized that the officer or man engaged in running the engines and boilers of a ship is doing just as much to defeat the enemy as the officer or a man who is operating the guns and turrets of the ship. Their skill, both mechanical and personal, is utilized for one military purpose, that of fighting the ship. Without practical engineering and practical ordnance experience the man on the bridge cannot be as efficient as with this practical knowledge. The more he knows about the driving power of his ship from experience below, the better is he fitted to command a ship or a division or a fleet, and the better qualified he will be in tactic and in strategy. It is a false theory that some men shall give themselves to problems of battle practice, others to engineering and to ordnance. The great commander is greater if he has been trained in all, for knowledge of engineer and ordnance duties is essential to the highest when in command in modern machine warfare.

The Navy is first of all a great practical University, with schools for teaching all the way from the three R's to the highest naval strategy. Our greatest officers are students and teachers. Every man in the Navy is a student. When he quits studying he ought to quit the Navy. When Admiral Sims concluded his great work abroad, he thought—and who will deny he was right—that the highest duty he could perform to increase the initiative and efficiency of the Navy was as President of the War College, the head of our great university and extensive educational system. The future of the Navy depends upon the vision to see and translate the larger problems of naval equipment and naval strategy. Here in the Post Graduate School, at the War College, at the Naval Academy, at all the schools is the real motive power which must drive the Navy upon larger seas and for broader usefulness.

In considering the broad field of Engineering and the accomplishments

of the Navy in this science, it is inspiring to know that one of the greatest achievements of our Navy during the past half century is the adaption of electric propelling machinery for our huge battleships. Too much praise for this advance cannot be given to Rear Admiral R. S. Griffin, Chief of the Bureau of Steam Engineering, to Mr. W. L. R. Emmett of the General Electric Company, and to the other engineers in civil life who have joined our naval officers in bringing this unique and far-reaching accomplishment to a successful issue.

The suitability of the electric drive for naval vessels was under discussion by our experts for several years: it is first tried out on the collier *Jupiter*, where it met every test as to economy, facility of operation and endurance. As a result of the very satisfactory service of the *Jupiter*, it was decided to adopt this type of machinery for the battleship *New Mexico*, and her successful operation has given great gratification to every one concerned since these results are a notable monument to American progress in the field of engineering.

The electric drive meets, in a peculiar way, the many requirements of battleship propulsion. Generally speaking, it is more economical, with a resultant saving of a large amount of fuel, thus making the battleship a more effective fighting machine, as it gives her a larger radius of action. It is also capable of withstanding long and hard service, and the cost of repair and upkeep is much less than that of any other type.

With the electric drive, the battleship can also be given an enormously greater protection against torpedoes and mines. This follows, since the various units of the machinery can be isolated in watertight compartments so the one or more torpedo explosions might occur in the machinery spaces, and such explosions would not only fail to sink the ship, but she would be able to continue at a very high rate of speed. For instance, one of the two main turbo-generators could be destroyed by a torpedo and the compartment flooded, and yet the ship could continue to run at about three-quarter of her maximum speed. This, for a fighting ship, is an advantage of the greatest value.

Again, the electric type of propelling machinery is peculiarly flexible in its operation, so that the ship can be driven at low as well as maximum speeds, with very nearly the same relative percentages of economy. This flexibility arises from the fact that changes can be made in electric circuits almost in the twinkling of an eye, while other types of propelling machinery must be designed to obtain the best economies at some particular speed, or else a compromise must be made to meet the extremes of high and low speeds.

The adoption of the electric drive is also a notable indication of the knowledge of engineering science which now exists generally among the officers of the Navy, and is as well a tribute to the high training and marked skill of the civilian engineers and naval experts who brought this epoch-making design to a successful finish.

This is peculiarly true, since it was this expert knowledge which prevented the opposition of some eminent civilian engineers against such a radical departure in battleship machinery from blocking the installation of the electric drive in the *New Mexico*. And, it served also as a bulwark against the business interests of those shipbuilders who, for reasons of their own, opposed this far-reaching development.

It is true that there were some officers of the Navy who hesitated in advocating so revolutionary an advance, fearing that it would be perhaps a hazardous experiment to make on so large a scale in a capital ship. Some thought that there might be serious danger in using the large voltages which would be necessary, and which might in some way be a menace to the ship.

All such fears have proven groundless, however, and our pride may well be stirred by the fact that the United States Navy was the first in the world to drive a battleship by electrical power and to do this with full success in every way.

In all this, we have but won another in the long list of triumphs which have given American engineers so high a place among the world's leaders in invention and mechanical progress—those pioneers whose work, in applying nature's resources to the use of man, has been of such inestimable service to our race.

SCAVENGING IN TWO-STROKE-CYCLE DIESEL ENGINES.

By Nicholas M. Trapnell.

The purpose of scavenging is to clear the cylinder of burnt gases at the end of the power stroke and to fill it with fresh air ready for compression. This article describes methods of scavenging and types of scavenging pumps.

Scavenging in the two-stroke-cycle Diesel engine is accomplished by admitting air, at a pressure of from 3 to 6 pounds per square inch, to the

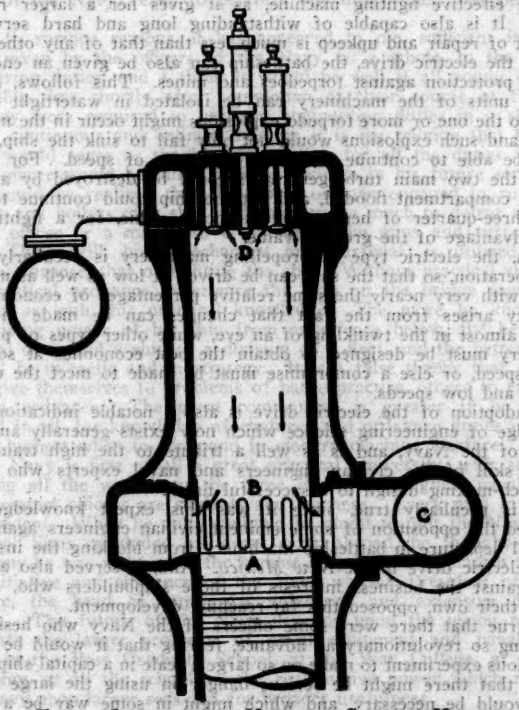


Fig. 1. Scavenging by Valves in Cylinder Head.

cylinder in such a manner that it forces the products of combustion out through the exhaust ports and fills the cylinder with air ready to be compressed on the next stroke of the piston. There are several methods of admitting the air to the cylinder. The first method used was by means of valves in the cylinder head, as shown in Fig. 1. As the piston A nears the end of the power stroke it uncovers the exhaust ports B in the bottom of the cylinder, which allows the exhaust gases to blow out into the exhaust pipe C. Shortly after the piston begins to uncover the exhaust ports, the scavenging valves D in the cylinder head open and allow the scavenging air to sweep down, forcing the products of combustion out through the exhaust ports and filling the cylinder with fresh air. The piston then starts on the return stroke and closes the exhaust ports after which the scavenging valves close and compression begins.

The scavenging valves are usually set to open some time after the piston has begun to uncover the exhaust ports, so as to allow the pressure in the cylinder to drop nearly to that of the atmosphere before the valves open; otherwise there is danger that the exhaust gases will back up through the scavenging valves into the scavenging-air receiver. The valves are usually set to close shortly after the piston has closed the exhaust ports, thereby allowing the pressure in the cylinder to build up to that of the scavenging-air receiver and giving a slightly higher pressure at the end

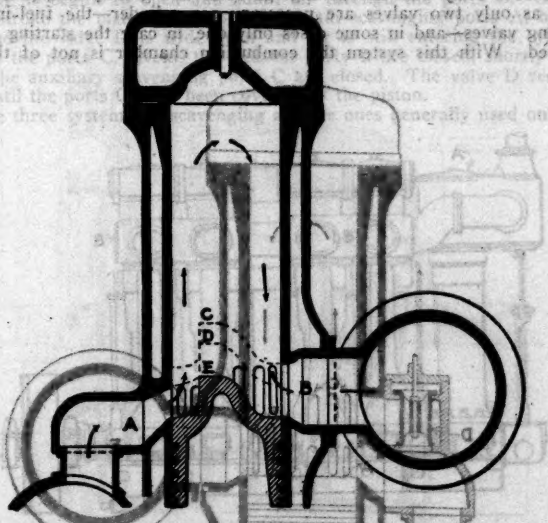


FIG. 2. SCAVENGING BY PORTS IN CYLINDER WALL.

of the compression stroke than would be the case if the scavenging valves closed as soon as the piston closed the exhaust ports.

This method of scavenging is very rapid and efficient and is extensively used in the smaller engines; but, as a large valve opening is necessary to admit the required amount of air to the cylinder, usually two and often four valves per cylinder are necessary in the larger engines. This leads to excessive complication of the valve gear, especially in large engines,

where six valves per cylinder would be necessary, including the fuel-inlet and starting valves. Also, the excessive number of valves greatly weakens the cylinder head, which should be pierced by as few openings as possible because of the high pressures and temperatures reached in Diesel-engine cylinders.

To overcome these difficulties a system of scavenging was developed which is now extensively used on large two-stroke-cycle engines. In this system, shown in Fig. 2, ports are used instead of valves. The scavenging ports A are arranged in the cylinder wall near the bottom of the cylinder opposite the exhaust ports B. When the piston reaches the position C in the power stroke, it begins to uncover the exhaust ports B and allow the products of combustion to escape to the exhaust pipe. When the piston has reached the position D, the pressure in the cylinder has dropped nearly to that of the scavenging air and the scavenging ports A begin to open and admit the air to the cylinder. When the piston has reached its final position E, all ports are open wide. The incoming scavenging air is deflected upward by the shape of the piston, so as to drive out all the exhaust gases. On the return stroke, the piston first closes the scavenging ports and then the exhaust ports, after which compression takes place.

This system is slightly less efficient than the valve scavenging system, but it does away with all scavenging valves and greatly simplifies the engine, as only two valves are necessary per cylinder—the fuel-inlet and starting valves—and in some cases only one, in case the starting valve is omitted. With this system the combustion chamber is not of the most

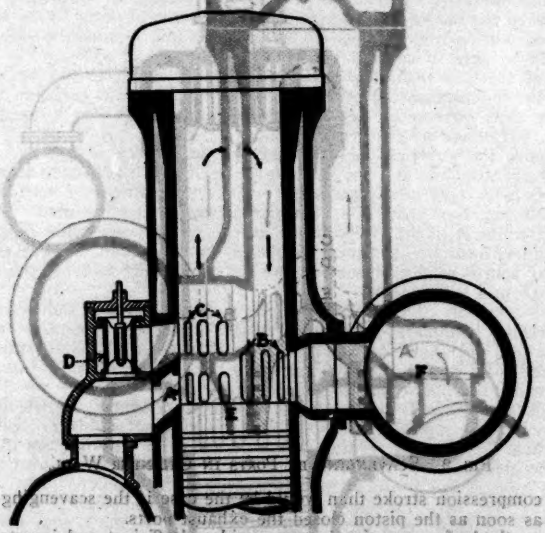


FIG. 3. SCAVENGING BY MAIN AND AUXILIARY PORTS.

efficient form, because of the shape of the piston. It should be as nearly symmetrical as possible and should contain no pockets or cavities. Also the compression is not so high as might be, because the scavenging ports

are closed before the exhaust ports, so that compression starts from atmospheric pressure instead of from 3 to 6 pounds per square inch, as is the case where scavenging valves are used.

Fig. 3 shows the system of scavenging used on an engine of the two-stroke-cycle type. The combustion chamber is not distorted and the scavenging ports are allowed to remain open for a short time after the exhaust ports have been closed. The main scavenging ports A are arranged half-way around the circumference of the cylinder at the bottom, opposite the exhaust ports B. Directly above the main scavenging ports A are the auxiliary scavenging ports C. The admission of air to these ports is controlled by the auxiliary scavenging valve D, which is operated by an eccentric on the engine camshaft. The scavenging ports are inclined so as to deflect the air upward and thoroughly scavenge the cylinder.

As the piston E nears the end of the power stroke it first uncovers the auxiliary scavenging ports C, but no air is admitted through these ports because the valve D remains closed. It then begins to uncover the exhaust ports B, which allows the product of combustion to escape to the exhaust pipe F. When the piston has reached the end of the stroke, it has completely opened the exhaust ports B and also the scavenging ports A, thus allowing air to enter the cylinder from the receiver. At this time the valve D begins to open and admit air through the ports C. On the return stroke the piston first closes the main scavenging ports A, but by this time the valve D is wide open and air is still entering the cylinder through the ports C. Next, the exhaust ports B are closed, shortly after which the auxiliary scavenging ports C are closed. The valve D remains open until the ports C have been covered by the piston.

These three systems of scavenging are the ones generally used on two-

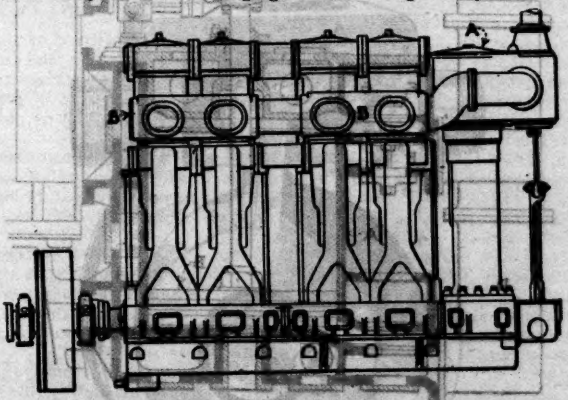


FIG. 4. ARRANGEMENT OF SCAVENGING PUMP AND AIR RECEIVER.

stroke-cycle Diesel engines. There are a few other systems used, but they differ only in minor details from the ones described.

The air for scavenging is obtained from the scavenging pumps, which are of the low-pressure reciprocating type and have a large capacity. The pumps are usually driven by the main engine, either from the crankshaft or by means of levers and rods connected to the cross-heads or connecting-rods. In marine work two pumps per engine are usually furnished,

so that in case one breaks down the other will deliver enough air to keep the engine running, as each pump has about 60 per cent of the total capacity required to run the engine.

The scavenging pumps discharge into a receiver, usually of small dimensions, which runs the whole length of the engine and supplies air to each cylinder for scavenging. This arrangement is shown in Fig. 4, in which A is the scavenging pump discharging into the receiver B which supplies air to the cylinders.

Very often large engines are divided into two sections; that is, a 4-cylinder engine is treated as two 2-cylinder engines and a 6-cylinder engine is treated as two 3-cylinder engines, one scavenging pump supplying each section. On very large double-acting engines one scavenging pump per cylinder is often used.

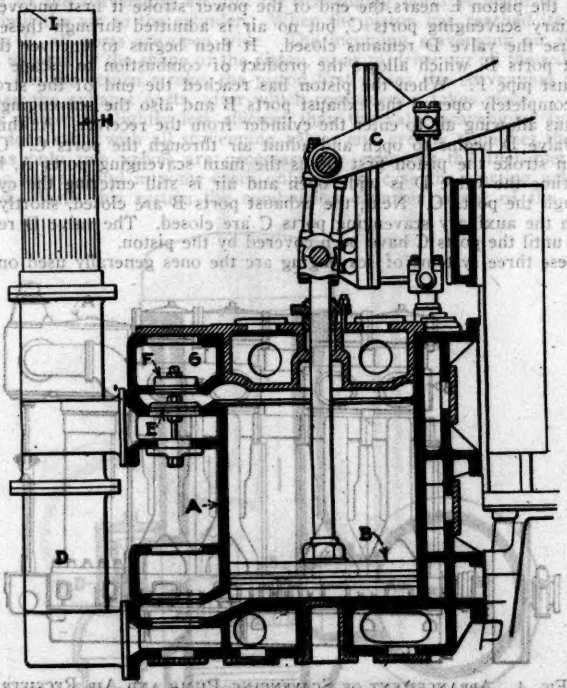


FIG. 5. CROSS-SECTION OF TYPICAL SCAVENGING PUMP.

Fig. 5 shows a cross-section of a typical scavenging pump. The cylinder A is mounted on the engine frame and the piston B is driven by the beam C, which in turn is driven, through links, from the crosshead of the main engine. The air is drawn from the suction pipe D, through the suction valves E, into the cylinder A, and is discharged through the discharge valves F into the passage G which leads to the scavenging air receiver. The flat or grid valves commonly used in this type of pump are closed by

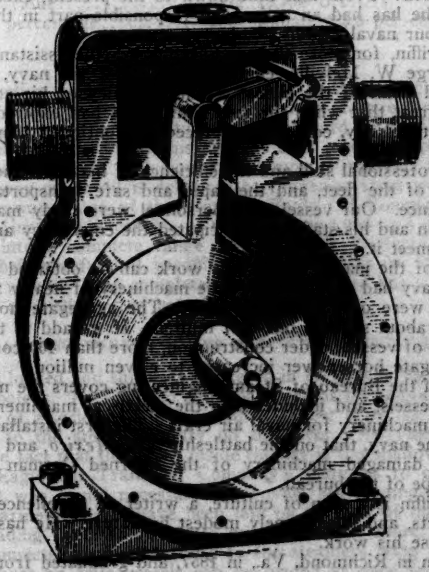
their own weight or by light spiral springs. Air enters the suction pipe D through the vertical slots H in the cylinder I, which acts as a silencer and strainer.

In the designing of scavenging pumps, the most important point is the provision of an ample supply of air, but it is difficult to say what should be the exact capacity of the pumps relative to the working-cylinder volume. That it must be in excess of the latter is generally agreed. For ordinary marine engines and low-speed stationary engines of the two-stroke-cycle type, the volume of the scavenging pump is frequently made 25 per cent greater than that of the working cylinder, while in high-speed engines it is often made 50 per cent greater.

Lately, turbo-blowers have been substituted for scavenging pumps in a number of cases. The results have been satisfactory, as a properly designed turbo-blower is capable of delivering a large volume of air at a pressure high enough for satisfactory scavenging, and it will undoubtedly be used extensively in the future, because of its simplicity and ease of regulation.—"Power."

THOMPSON RETURN-LINE VACUUM PUMP.

In a vacuum heating system the condensation from the radiators, together with the air, is drawn by suction to a pump, where the air is separated from the water, and the hot water is returned to the boiler or to a receiver. Naturally, a vacuum pump should be simple in construction, quiet in operation and durable.



SECTION THROUGH VACUUM PUMP.

The illustration shows a pump that has but three moving members, the crank and the impeller, and a hinged plate, the purpose of which is to separate the suction and the discharge side of the pump cylinder. The surfaces of the impeller and the pump casing are cylindrical, and the impeller is at no time in contact with the casing, a very close clearance being maintained. The crankshaft of the impeller is fitted with ball bearings, and as the crank turns in a clockwise direction, it gives the impeller an eccentric motion. As the water enters the inlet pipe it discharges into the space between the rotor and the casing, and as the rotor revolves this water is carried around until it escapes through the discharge pipe. This pump is being manufactured by the Thompson Manufacturing Co. of Des Moines, Iowa.—"Power."

ADMIRAL GRIFFIN RECEIVES HONORARY DEGREE.

The honorary degree of Doctor of Engineering was conferred upon Rear Admiral Robert S. Griffin, engineer-in-chief of the United States Navy, by the Stevens Institute of Technology of Hoboken, N. J., on June 17. While comparatively few, outside of those intimately connected with naval engineering affairs, are aware of the vast scope of his activities, and especially the responsibilities carried during the period of the war, it will be a source of gratification to his friends and associates to learn of this richly deserved honor.

The new navy may be considered as commencing with the Roach cruiser about 1885, at which time Admiral Griffin was an inspector of machinery for those vessels. From that time down to the present, except for tours of sea duty, he has had an active and responsible part in the equipment efficiency of our naval vessels.

Admiral Griffin, for more than five years, was the assistant of the late Admiral George W. Melville, engineer-in-chief of the navy, and in 1913 was appointed chief of the bureau. The efficiency of his administration has been so great that when the four-year detail had expired in 1917 the Secretary of the Navy, contrary to precedent, continued him as chief of the bureau.

Upon his professional skill and the efficiency of his department depended the readiness of the fleet, and the rapid and safe transportation of our armies to France. Our vessels and personnel were ready mainly because Admiral Griffin and his staff had anticipated the emergency and had plans completed to meet it.

Some idea of the magnitude of this work can be obtained by considering that the navy had under its care the machinery of nearly 2,000 vessels, of which 570 were of our regular navy. The aggregate horsepower of these ships is about six and one-half million. If we add to this the total of the number of vessels under construction, more than 400 could be added and the aggregate horsepower increased to eleven million.

The work of the Bureau of Steam Engineering covers the motive power of all naval vessels, and includes also the electrical machinery, the radio telegraph and machinery for naval air craft. The first installation of electric drive in the navy, that on the battleship *New Mexico*, and the rehabilitation of the damaged machinery of the interned German ships, came within the scope of the bureau.

Admiral Griffin is a man of culture, a writer of excellence upon engineering subjects, and is extremely modest by nature. He has never been one to advertise his work.

He was born in Richmond, Va., in 1857, and graduated from Annapolis in the class of 1878.—"Power."

FUEL OIL.

Mr. A. F. Baillie on its Production and Applications.

Mr. A. F. Baillie, of the Engineering Department of the Anglo-Mexican Petroleum Company, Limited, read a paper on "Fuel Oil: Its Production and Applications," on February 8, before the Birmingham Association of Mechanical Engineers.

After dealing with the origin, history and chemistry of petroleum, he pointed out that fuel oil was frequently spoken of as "crude oil," but this is incorrect, as the crude oil—that is, the petroleum oil as it issues from the well—contains certain light fractions of the gasoline and kerosene series, which it is not only desirable to extract from the crude by distillation on account of their higher values, but which if left in the fuel oil and used as fuel, would be a wasteful procedure, and, further, would lower the flash-point, which has been very properly fixed by British authorities, viz.:—Lloyd's Register of Shipping, 150 degrees Fahr.; British Admiralty, 175 degrees Fahr.; London County Council, 175 degrees Fahr. The crude is therefore subjected to what is known as a "topping process," which is a distillation which cuts out those lighter fractions, leaving a product having a calorific value of about 19,000 B.T.U.'s per pound.

The physical and chemical tests of Mexican fuel oil are as follows:

Specific gravity	under .95 at 60 degrees Fahr.
Flash point (open).....	over 150 degrees Fahr.
Viscosity.....	under 1,500 seconds (Redwood) No. 1 at 100 degrees Fahr.
Calorific value.....	over 18,750 B.T.U.'s.
Sulphur percentage.....	approximately 3.5 per cent.

Pipelines, Storage and Refining.

The production of oil is only the first link in the long chain of operations. The crude oil has to be transported to storage tanks at the refineries, which are generally situated on seaboard to facilitate shipment of the refined products. For this purpose steel pipelines are employed of 8 or 10 inches diameter, with powerful pumps at intervals along the line, and in this way crude oil is delivered to refineries from wells which are many miles away. One of the Mexican Eagle Oil Company's refineries, situated at Minatitlan, is capable of turning over 1,000 tons of crude petroleum daily into a complete range of high-grade products, *i.e.*, gasoline, kerosene, lubricants, fuel oil, paraffin wax, and asphalt for roads. Another refinery has recently been completed at Tampico, and has a total throughput capacity of 3,000 tons of petroleum per day.

Loading, Bunkering and Marine Transportation.

Fuel oil is loaded and ships are bunkered in Mexico at Tampico, Tuxpam and Coazacoalcos. At Tampico and Coazacoalcos the operation of loading is by means of a series of 8-inch pipelines leading from the refinery pumping station to the steamer's jetty on the river. At Tuxpam, however, owing to the fact that the water inside the bar is too shallow for the large 15,000-ton Eagle Oil Transport Company's steamers to come alongside and load, it was found necessary to provide sea loading-lines. Accordingly, submarine pipelines have been laid on the bed of the sea, reaching out to a loading terminal about 1½ miles from the shore. The pipelines are then connected by flexible hose to the steamers lying at these moorings, and three or four vessels can be loaded at once from the storage tanks and pumping station on shore. On an average each steamer is

loaded and despatched within two and a half days, as the pumping and sea-line facilities enable a ship to be loaded at the rate of 10,000 tons per 24 hours.

The next step is the transport from the refineries to the world's markets, for which purpose a large fleet of tank steamers, of over 15,000 tons deadweight capacity, have been built by the Eagle Oil Transport Company. The latest addition to this fleet is the *San Florentino*, which has a deadweight carrying capacity of 18,000 tons, and is the largest oil tank steamer in the world. This vessel, which has a greater displacement than a dreadnought, was recently launched on the Tyne, and is now being fitted with geared turbines and oil-fired boilers.

The tanks of these vessels are fitted at the bottom with heating coils, which enable them to transport not only ordinary grades of fuel oil, but also the heaviest Mexican fuel oils, in bulk during the winter months, the fuel oil being loaded in Mexico at a temperature of 100 degrees Fahr., allowed to cool down to about 85 degrees Fahr. during the voyage, and when the vessel is about three days from the home port these steam heating coils are brought into play and the temperature again raised to about 100 degrees Fahr., to facilitate speed of discharge. Four large steam-driven cargo pumps are installed, and are fitted as close to the bottom of the ship as possible, so as to obtain the minimum suction lift. These pumps are capable of handling 1,200 tons, or 7,500 barrels of oil per hour.

The tank steamers discharge their cargoes into ocean storage installations at various ports in this country and abroad, into storage tanks ranging in capacity from 30 to 8,000 tons. The largest tanks in this country have a capacity of 6,600 tons, and are 95 feet in diameter by 37 feet high.

APPLICATIONS AND ADVANTAGES.

From a rapid survey of production and transport he passed to a summary of the applications of fuel oil and its proved advantages in comparison with coal.

(*a*) *Warships.*—During the war many thousands of tons of oil fuel have been supplied to the Admiralty. Not only has it been used in submarines, torpedo destroyers and fast cruisers, but the newest type of capital ships, such as the *Queen Elizabeth* series, are fitted to burn oil fuel only. Its use has without doubt contributed to our naval supremacy, notably in the battle of Falkland Islands. In 1915 Lord Fisher, the veteran advocate of an oil-fired navy, wrote as follows: "Machinery has no nerves, and the all-oil boilers do not get tired. No more hell in coaling ship. The unfailing propellers get us at top speed on the spot to a minute, though 7,000 miles away." This reference is obviously to the Falkland Islands battle, which was won in December, 1914.

The points in favor of oil in place of coal for warships are:—

(1) Radius of action increased by 50 per cent on equal bunker weight, or 80 per cent on equal bunker space.
(2) Up to 83 per cent thermal efficiency, instead of 60 per cent.
(3) Boilers can be forced up to 50 per cent above normal rating.
(4) Control of smoke: entire absence or dense smoke screen as desired.
(5) Reduction of labor by about 70 per cent.
(6) Constructional advantages.
(7) Bunkering at sea.

(*b*) *Mercantile marine.*—There are many equally attractive advantages in the application of oil to the mercantile marine. One interesting comparison on coal and oil was made by the American Hawaiian Steamship

Company's SS. *Arizonan*. This vessel took 161 days on the round voyage when burning oil, as compared with 186 days when burning coal, and by economies effected and increased earnings due to saving of bunker spaces, and decrease in operating staff, she saved $19,500 on the voyage, or over £4,000.

It is important to remember that the furnace of a vessel burning oil may be readily altered to burn coal, or *vice versa*, when required. If suitable arrangements are made the work can be done at the cost of a few pounds by the ship's own staff without any considerable trouble or delay to the steamer. The advantage offered by this ready conversion is that with vessels which trade between countries where either coal is dear and oil cheap, or the reverse, the cheaper fuel can be used on both journeys, resulting in remarkable economies. The Toyo Kisen Kaisha steamship line is operated in this way.

Another instance is a comparison of the Eagle Oil Transport Company's vessels *San Dunstano* and *San Eduardo*, both vessels of 9,000 tons deadweight carrying capacity, which are fitted to burn coal and oil respectively. The consumption of fuel worked out at two to three in favor of oil, while the I.H.P. developed showed an 18 per cent improvement in the case of the oil-fired vessel. The striking fact of the comparison is that the *San Eduardo* made the round voyage to Mexico and back eight days quicker than the other, making a large improvement in her earning capacity.

On a comparative test run at Wallsend Slipway on coal and oil on a Scotch marine multitubular-type boiler the following results were obtained:—

MEXICAN FUEL OIL.

Fuel Oil—	
Specific gravity at 60° F.	.953
Viscosity at 100° F. (Red. No. 1)	2,130 secs.
Flash point (close)	160° F. (above)
Calorific value	18,430
Water evaporated—	
Lbs. of water per lb. of oil	12.15
Lbs. of water per lb. of oil (from and at 212° F.)	14.38
Boiler efficiency	73.37 per cent

COAL.

Coal—	
Calorific value in B.T.U.	14,432
Water evaporated—	
Lbs. of water per lb. of coal	7.76
Lbs. of water per lb. of coal (from and at 212° F.)	9.31
Boiler efficiency	62.28 per cent

Efficiencies as high as 84.5 per cent have been obtained in this country on Scotch marine type boilers, using Mexican fuel oil with the pressure system of oil burning.

At a large London factory which converted their Lancashire boilers from coal to fuel oil firing, the water evaporation per pound of coal having a calorific value of 11,451 B.T.U. was 7.22 pounds, whereas when working with the pressure system of oil burning, using an oil having a calorific value of 18,750, the evaporation per pound of oil reached 14.44 pounds. The quantity of water evaporated per square foot of heating surface on coal was 3.3 pounds, whereas oil showed over 7 pounds, thereby increasing the boiler rating by over 100 per cent.

METALLURGICAL FURNACES AND BURNERS.

Fuel oil in this country is mainly used in industrial furnaces, such as billet heating, metal melting, riveting, bolt and nut making, and the manufacture of glass bottles.

The largest quantity of oil fuel used in 1917 for furnace purposes was for billet heating in connection with the manufacture of shells. In pre-war times the principal consumers were glass-bottle manufacturers and rivet, bolt and nut makers. In post-war times we may see a drop in the consumption of billet heating, but we hope to see a large increase in the consumption for glass manufacture. Again, large users of oil fuel are found in the metal-melting industry, melting metal from the low-fusion aluminum to the high-fusion steel. The melting-points of these range from 1,000 degrees to 3,000 degrees Fahr. (approximately 540 degrees to 1,650 degrees Cent.) In the manufacture of wrought iron materials these are usually forged to drop stamped, and for this purpose it is necessary to heat the metal up to a temperature of approximately 2,500 degrees Fahr. (approximately 1,370 degrees Cent.). This heat was formerly obtained by means of placing iron bars in a coke furnace of the type used by the wayside smith, but of larger dimensions and with improvements. This, until gas or oil fuel was introduced, was rather a slow process, and since oil fuel has been used in an intelligent manner the output of each new or converted furnace has been almost trebled.

Another point which is worthy of notice and which usually appeals to every works manager, is the fact that when utilizing oil fuel the size of the furnace is reduced by 30 per cent, and the working area occupied by a furnace and its adjacent machines is only about 50 per cent of that of the coal-fired furnace, as a stack of coal occupies a certain amount of space in front of the furnace, and the resultant ashes occupy another space behind the furnace.

The next interesting manufacture is that of metal melting. The principal metals which have been melted during the war are aluminum and what is known as "70/30 brass," aluminum being principally used for aeroplanes and motor car work, 70/30 brass being principally used for cartridges.

AUXILIARY TO COAL AND GAS.

In the early years of this century a French engineer introduced the subject of oil as an auxiliary fuel, a combination to which little attention had been paid in the past. The main advantages of auxiliary firing, he remarked, lay in being able to obtain at will a large increase in the power of boilers, also that the combustion of the petroleum does not in any way prejudicially affect that of coal. In fact, by the introduction of jets of petroleum the condition and efficiency of combustion are improved by more completely mixing the gases. It is therefore not correct to consider the evaporative power of coal as identical, when passing from ordinary to auxiliary firing. Admitting this as a principle, and supposing the quantity of water evaporated by the coal to be constant, the extra evaporation, due to the better mixing of gases, is credited to the petroleum.

Several evaporative trials were made with coal only and coal and oil firing on the same boiler of a French Navy ship, with the following results:—

Test No.	Fuel Used: Coal Per cent	Fuel Used: Oil Per cent	Lbs. of fuel per sq. ft. of grate area	Water evaporated per lb. of fuel used	Remarks
1	100	..	18.8	9.05	
2	55	45	21.3	11.34	25 per cent evaporative increase over No. 1.
3	36	64	21.7	14.12	56 per cent evaporative increase over No. 1.

These tests were encouraging, and should have served as a basis for further experiment, but the question was not developed until about four years ago, when power station engineers started taking a keen interest in the subject. Their theory was that a poorer class of coal could be used in conjunction with oil fuel than could be burned satisfactorily by itself under the boilers, this being due to the fact that the poor class of coal tended to cake on the links of the chain grate stokers, thereby retarding the necessary quantity of air being drawn through the bars to complete combustion.

The result was that the poor classes of coal were merely covered with a smoldering mass, which traveled slowly along the bars and were dumped into the ashpit. This ash, on analysis, contained a very high percentage of partly consumed coal, thereby causing a very much higher quantity of coal to be burned to maintain any rated evaporation that would have been used if a better-class coal were employed.

When auxiliary fuel oil is applied, the theory is that as a result of the almost perfect combustion obtained thereby, the combustible gases rising from the coal fuel bed were quickly ignited causing the top of this mass to become much more incandescent, thereby tending to aerate the bottom mass, which would then allow sufficient air to be drawn through to complete the combustion of the rest of the coal.

Sufficient interest was taken in this theory for a large London power station to give their sanction for tests to be carried out under one of their coal-fired Stirling water-tube boilers. One burner was introduced into each side of the boiler, approximately about 25 per cent from the back of the grate, the burners being opposite one another. The fuel oil was stored in an overhead tank, capable of holding three or four days' supply. The oil then gravitated to the burners, which were of the Kermode steam jet type, operating with steam as an atomizing agent at a pressure of about 25 pounds per square inch.

The final of a series of experimental mixed-fuel tests was carried out on a nutty slack, having a calorific value of 10,300 B.T.U.'s and Mexican fuel oil, having a calorific value of 18,750 B.T.U.'s. A boiler efficiency of 74 per cent was obtained, and the temperature of the combustion chamber was 2,850 degrees Fahr. and uptake 628 degrees Fahr. The proportion of oil to coal on a B.T.U. basis was 8 per cent and on a weight basis 4.96 per cent.

Assuming coal at 20s. 10d. per ton and oil at 50s. per ton, the cost per ton of water evaporated using coal only was 2.8s., and using the aforementioned percentage of coal and fuel oil 2.62s., showing a monetary saving of 6 per cent.—"Shipbuilding and Shipping Record."

THE EXAMINATION OF MATERIALS BY X-RAYS.

The general discussion on "The Examination of Materials by X-Rays" by a joint meeting of the Faraday Society and the Röntgen Society, held in the rooms of the Royal Society recently, clearly brought out the great possibilities as well as the limitations and difficulties of this promising

method of testing materials, which excites far wider interest than might be supposed from the sporadic notes and papers so far published. Great credit is due to Sir Robert Hadfield, Bart., F.R.S., for the initiation of this discussion over which he presided, as president of the Faraday Society, supported by Dr. Batten, the president of the Röntgen Society. The meeting was opened at 5 p.m., resumed after a dinner interval at 8:30, and did not disperse till near 11 o'clock. That is nothing unusual for the Faraday Society. As it was, the remarkably good collection of exhibits by scientists and firms did not receive the attention it deserved, because the instructive character of the discussion kept members within the lecture hall, though several speakers were restricted by official ties. With a very natural pride, Sir Robert Hadfield dwelt upon the fact that this was the twentieth general discussion arranged by the Faraday Society, nearly all as successful and crowded as on last Tuesday, when the Society for the first time enjoyed the hospitality of the Royal Society. This is a remarkable record for a comparatively young society of a little more than 300 members. As Sir Robert has occupied the chair during the whole war period, he has presided over a good many of these meetings to the success of which, it should be added, he has contributed in manifold ways. Mr. F. S. Spiers, B.Sc., to whose valuable services Sir Robert expressed the society's indebtedness, has been secretary since the foundation of the society, the offices of which are at 82 Victoria street, Westminster.

In his introductory remarks Sir Robert Hadfield said that, when suggesting a general discussion on Radiometallography, he had been quite aware that such an examination for flaws might, if unfairly used, cause manufacturers great trouble and expense, and he had certainly not wished to cast any doubt on the wonderful improvements of the last decades in metallurgical production. His own firm, he might state, had been turning out 8,000 9.2-inch high explosive shells weekly at one time during the war—other firms had done similar big things—and in spite of all the pressure and hurry there had not been a single instance of their products failing through defects; that applied also to some 6,000 guns and tubes for guns, etc. But technologists had to study every new means of ensuring perfect materials. So far X-ray examination seemed limited to thin sections of metal, though some experimenters had dealt, in this country, with specimens of 4-inch and even of 9-inch thickness. Sir Robert had himself submitted to Professor Bragg a large number of purest specimens obtainable in the hope that the X-ray study would clear up the differences in the physical properties of the metals of the iron groups, and the magnetic and other peculiarities of critical points and of allotropic modifications. Those specimens included pure electrolytic iron, various kinds of steel, overheated, cast, etc., several alloys, and manganese metal, cobalt, chromium, tungsten, molybdenum in various conditions. Proceeding to a review of the literature on the subject, which he had conveniently summarized in a bibliography at the end of his paper, Sir Robert drew attention to the X-ray examination of flaky steel by H. S. Rawdon, of Washington—we had a Note on this subject in our issue of last week—to the equipment for X-ray examination which the firm of Henri Pilon had supplied to Messrs. Schneider and other firms; and to two recent German publications on the subject, which Sir Robert had had translated on account of their generally instructive and practical character. Professor Porter subsequently gave an abstract of these papers, copies of which were distributed. Sir Robert Hadfield's own contributions to the researches will presently be mentioned.

In his opening address, Professor W. H. Bragg, C.B.E., F.R.S., of University College, London, stated that it was one of the chief purposes of the conference to display the possibilities of X-ray methods to those who

had no occasion to make a study of X-rays themselves. X-rays were of the same nature as light, but of extremely short wave-lengths. Whilst ordinary light gave us information relating to the outward form, the X-rays passed right through a body and revealed its interior condition. For practical purposes X-rays were excited by causing a powerful electric discharge to take place within an exhausted bulb (Coolidge tube), in which the discharge fell on a block of metal, the target or anti-cathode. The actual impact was limited to a small area of the target, the focus; a large amount of the energy unfortunately went into heat, and ingenious devices were adopted to get rid of that heat. The quality of the rays depended upon the target material, tungsten or platinum in the Coolidge tube, but not upon its temperature, and though even rays from tungsten were not quite satisfactory in quality, we had to use such refractory metals which would stand the rise of temperature. For good definition of the radiographs, the focus should be "fine"; but a fine focus would not take much power. The rays emitted from the target in all directions had three main effects; they excited photographic plates and phosphorescent screens, and they ionized gases. The last effect was useful in the laboratory, the second in surgery, but hardly in metallurgy and engineering, and the action on photographic plates would probably be the basis of engineering practice.

The X-rays had the extraordinary property of passing through all substances more or less. The shortest, hardest rays, produced by the highest potentials, had the greatest penetrating power, and might alone prove useful in engineering. The transparency of a material to X-rays decreased as the atomic weight increased. Heat had no influence; a red hot casting gave the same radiograph as a cold casting. But owing to that high penetrating power the rays could neither be focussed nor deflected by lenses or prisms. The penetration depended merely on the atomic weight and the thickness of the material. Professor Bragg exemplified this by a selection of beautiful radiographs. The positive of a watch clearly showed all the parts, wheels, springs, etc.; in a cherry blossom the delicate nerves of the petals were quite distinct; a tadpole which had swallowed a worm looked less dark than the worm which somehow seemed to consist of substances of higher atomic weight; in an electric kettle heater the wire, the porcelain and the star-shaped iron support all cast their shadows. In some photographs of good and faulty castings and welds the tool marks were quite distinct; considering how minute the differences in thickness due to the tool marks were, that fact indicated the truly remarkable sensitiveness of the method.

The explanation of that sensitiveness depended mainly on two considerations. When two X-ray beams of equal initial intensity passed through two slabs of the same material of different thicknesses, the ratio of the transmitted intensities depended only upon the absorption in the extra thickness of the one slab, but not at all upon the absolute thickness. If we imagined two beams to strike the photographic plate, the one passing first through steel, the other striking the plate directly, the intensity ratio of the transmitted beams, $T_1 : T_2$, was dependent upon the absorbing power of the steel; if further two equal blocks of some material were interposed in the two beams, both T_1 and T_2 would be reduced, but their ratio would remain the same. Secondly, we had to consider the way in which the photographic image was formed. The blackening of the plate, due to two rays of unequal intensities, increased with the intensity of the rays. The transparency of the plate diminished as the blackening increased, but the ratio of the transparency in two spots, the "contrast" on the plate, was not the ratio of the two ray-intensities. Supposing we had two rays, one twice as intense as the other, and that in the case of the

stronger ray, the passage for each period of time reduced the transparency to half its value. In the case of the weaker ray it would always take two periods of time to reduce the transparency to half its value, and when the two transparencies were compared at any time they would be found not to be always in the ratio 2:1. By under-exposure and over-exposure any desired contrast might be obtained, but other circumstances came in, and the plates might become too black; yet by proper manipulation visible contrasts would be secured. Professor Bragg mentioned that Dr. Slade would deal with these points more fully.

Professor Bragg then returned to the question: should hard or soft X-rays be used? For penetrating through the material the rays should be hard; but then they penetrated also through the plate, and we had to increase their action on the plate. That action was due to the liberation of electrons which darted to and fro among the surrounding atoms until their energy was spent. In the emulsion, electrons were set in motion mainly through absorption of X-rays by the silver and bromine, and that action might be reinforced by putting heavy atoms into the emulsion. Some experimenters placed a thin lead sheet on the film, so that the electrons generated in the lead struck back into the photographic plate. The variation in the absorption of rays of different wave-lengths, studied by the Duc de Broglie and others, suggested a further consideration. As wave-length increased the absorption by a given substance also increased; but at a certain value, critical for each substance, the absorption suddenly dropped, to rise again steadily afterwards. There was, therefore, a "step down" in the photograph—it should not be called a band—marking the critical wave-length for silver. A similar "step up," on the side of short wave-length, would be obtained by interposing an absorbing screen, say of antimony or some other metal, in the path of the rays. That "antimony line" was so sharp that it might serve for a new method of spectroscopic examination of the constituents of a material. We might also put some special material in the emulsion and choose X-rays intermediate between the actual value of this material and of the casting under test; but this did not appear practicable. Professor Bragg finally referred to the examination of crystal structures by X-rays, on which he has himself done pioneer work, and which has practical interest to metallurgists. The war, he concluded, had interrupted much X-ray research which might soon be resumed, he hoped.

A paper sent by Mr. E. Schneider, on "The Industrial X-Ray Examination of Metals at the Laboratories of Messrs. Schneider, Le Creusot," was then read in abstract. The radiographs, taken with the apparatus and Coolidge tubes of Messrs. Pilon, exemplified the remarkable influence of aluminum in eliminating blow-holes in fish-plates; the examination of steels containing different percentages of tungsten; and the examination of compound metals. A fault in a cast steel bracket of a gun carriage was revealed by X-rays and the method changed to avoid repetition of such flaws. The steel specimens so far tested do not exceed 45 mm. in thickness; but that limiting thickness is reduced when the steel contains a constituent of higher atomic weight.

Of the two German papers, already referred to, which Sir Robert Hadfield had had translated and which Professor A. W. Porter, F.R.S., of University College, London, abstracted, the one by Dr. Respondek, of Halensee, near Berlin, outlined "The Principles Governing the Penetration of Metals by X-Rays"; and the other, by F. Janus, of München, and M. Reppchen, of Köln, explained the "Investigation of Metals by Means of X-Rays." The latter paper was based upon researches conducted in the laboratories of the firm of Reiniger, Gibbert and Schall, A.G., of Berlin-Erlangen, and was in particular compiled for the technical man

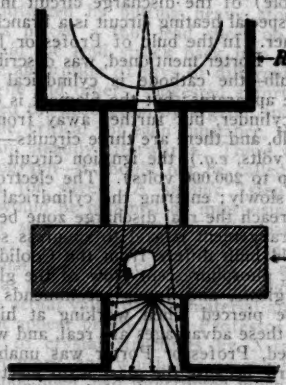
unfamiliar with Röntgen-ray bulbs. Perhaps we had better adopt a general tone in our notice, since Professor Bragg had purposely left several points to subsequent speakers.

In the ordinary Röntgen bulb (gas tube) positive ions striking the cathode drive out electrons from the cathode, which, in their turn, hitting the anti-cathode or target, give rise to the emission of X-rays from the target. For the examination of materials we want hard, uniform rays. When we depend upon the ionization of the gas molecules in the bulb, however, there will be soft as well as hard rays, and the hardness will change during the working. Hence bulbs of the Coolidge type came into use; in these the vacuum is pushed as high as possible. There are hence few gas molecules left that might be ionized, and the stream of electrons required for the causation of the X-rays is obtained by heating to incandescence a Wehnelt cathode or a thin wire of tungsten (the spiral or filament) by a special current; this spiral is surrounded by the cathode proper (the negative pole) of the discharge circuit in the bulb. In the Coolidge tube itself the special heating circuit is a branch of the secondary circuit of the transformer. In the bulb of Professor J. E. Lilienfeld, of Leipzig—which Professor Porter mentioned, was described in 1912, a year before the Coolidge bulb—the cathode is cylindrical and opposite the target as in the Collidge apparatus; but the filament is of large size; it is not placed within the cylinder, but further away from the target, in a lateral branch of the bulb, and there are three circuits—the heating circuit (potential difference 15 volts, *e.g.*) the ignition circuit (2,000 volts), and the discharge circuit (up to 200,000 volts). The electrons emitted by the hot cathode first travel slowly; entering the cylindrical cathode, they are accelerated before they reach the real discharge zone between the cathode and the target. The arrangement is said to suppress soft rays from the outset, and the Lilienfeld bulb differs from the Coolidge bulb as to the peculiar, little noticeable, phosphorescent glow of the glass walls. Lilienfeld has studied these glows, and Janus recommends his bulbs as less likely than others to be pierced when working at high potentials and temperatures. Whether these advantages are real, and whether the Lilienfeld tubes are much used, Professor Porter was unable to say. When gas bulbs become too hard, because the glass walls electrostatically attract the gas (air) molecules and remove them from the bulb, some air is admitted into the bulb from a pocket. This can be done automatically by the aid of a milliamperemeter acting as a relay. In any case, the discharge and hardness are regulated with the aid of an electrometer (called also penetrometer in this connection) and a milliamperemeter.

Light radiation passing through a substance will partly be reflected; part is absorbed, part scattered and part transmitted. The absorption of X-rays increases proportionally to the atomic weight in accordance with $J = J_o e^{-\lambda d}$, where J is the intensity of the absorbed radiation, J_o that of the incident radiation, e is the logarithmic base, λ the coefficient of absorption, and d the thickness of the substance. Instead of λ, μ is sometimes used, being defined by $\mu = \lambda/\rho$, where ρ is the density; the formula is then $J = J_o e^{-\mu\rho d}$. The absorptions may also be expressed in half-values (similar to the half-life period of radioactive substances), the half value indicating the thickness of the respective material which would stop half the radiation, expressed in centimeters (or fractions of a centimeter) of a foil of aluminum of equal stopping power. The following table summarizes the atomic weights A.W., densities ρ, μ/ρ and half values of a few metals for hard rays.

In order to secure sharply-defined radiographs the rays falling upon the specimen should be parallel and normal to the plate. As a matter of fact, the bundle of rays is conical, and the scattering still more impairs the

definition. The scattering takes place in all directions within the specimen and is not confined to the specimen, of course, but the whole air space, and objects in the room help to scatter; rays also fall upon the plate and table by the side of the specimen, and enter the plate from the sides and from below. In order to reduce the scattering the bundle of rays is confined within a tube of lead, and sheets of lead are applied to all the parts of the plate which might be excited by stray radiations. The diagram annexed (from the paper by Janus and Reppchen) illustrates the action in the case of thick specimens. The rays pass through a diaphragm in the bulb casing of lead, down the upper lead tube, through the specimen, down the lower tube and enter the plate, first passing through the intensifying screen which is interposed between the plate and the top of the plate carrier.



	A-W.	ρ.	μ/ρ	Half-Value.
Aluminium ..	27·1	2·6.	0·97	0·28
Iron	55·8	7·7	7.5	0·012
Silver	107·9	10·5	17.7	0·0037
Platinum ..	195·2	21·5	22	0·0015
Mercury ..	200·6	14·4	22	0·0022
Gold	197·2	11·4	22	0·0022

The secondary radiation from below is particularly troublesome with thick specimens; if lead sheets, up to 10 mm. thick, cannot conveniently be used, cast lead may be employed, or lead-shot be piled on the parts. For the protection of the operator the bulb is placed within a brick chamber which is fitted with a window of one or several layers of lead glass; switches are mounted on the outside of the wall; further information on these points was given in the paper by M. Pichon.

The photographic films must be thick and rich in silver; a slow developer (glycocoll) has to be used, as a rapid developer would fog the surface. The exposure may have to be long, but can be much shortened by the aid of intensifier screens (*e.g.*, of calcium tungstate), which are placed

over the plate. The blue light of the tungstate reduces the exposure, to one-sixth and even much smaller fractions; these screens are delicate, however, and easily stained; they impress the grain of the tungstate crystals on the radiographs and are, according to Janus, apt to impair the definition; the point was not raised during the discussion. With a distance of about 30 mm. between cathode and target, the specimen should be about 40 cm. below the focus of the bulb. In the examination of tubular specimens, the films are placed inside the specimen. Blowholes come out much better than cracks; unless parallel to the rays cracks are hardly shown by the X-rays. Faults near the upper surface appear more distinct than faults deeper down. The position of a flaw can be fixed in various ways. A simple method, not always applicable, however, is to take two radiographs on the same plate, shifting the plate laterally for the second exposure. During the exposure the bulb and apparatus must, of course, be kept perfectly steady, a condition not easily realized in works. In ferro-concrete any deformation or rusting of the iron bars can easily be detected. The clean iron gives sharp shadows, the rusty iron thicker, more hazy shadows; Respondek gave a good photograph of a ferro-concrete slab, 20 mm. in thickness, exposed to the rays for five minutes. X-ray testing of the quality of a cement, and the study of the chemical changes going on in cements, have so far failed.

A series of communications on researches carried out by Sir Robert Hadfield, Mr. S. F. Main, B.Sc., and Mr. J. Brooksbank, B.Sc., in the Hadfield Research Laboratory, Sheffield, were then presented. We hope to reproduce some of the photographs next week. The first on "Testing the Absorption Power of Different Steels Under X-Rays," dealt with some of the early experiments. Discs, 1 inch in diameter, one-thirty-second of an inch thick, were placed either on a barium-platinocyanide screen or on a photographic plate. The specimens were a very pure iron (0.03 C, 0.01 Si), density 7.78, forged; a steel with 1.19 C, 0.07 Si and 2.45 Al, density 7.37; and an alloy steel (0.55 C, 2.79 Cr, 20.4 W), density 8.77; the permeability decreased as the density increased, but the differences were not sufficiently marked when the fluorescent screen was used, and the addition of an intensifier proved advisable in the case of the plate. Similar discs, all of the very pure iron, were then prepared, increasing in thickness in steps of 1/64 inch from 1/32 inch up to 3/16 inch; a piece of thin, irregularly bent iron wire was placed over each disc to help bringing out contrasts; some other steels were tested at the same time. The thicker discs gave darker pictures (all negatives); but a hardened quenched steel disc produced a less dark negative than the annealed specimen. This was contrary to expectation.

The second paper on "X-Ray Examination as Applied to the Metallurgy of Steel," was of a general kind. Steel specimens up to 4 inches in thickness, it was pointed out, were said to have been successfully examined. To be of actual service the method should allow of examining articles of practical sizes; otherwise the chief advantage of the method, its non-destructive character, would be lost. The examination might be applied to routine examination of castings and forgings in the course of their manufacture, and also to the materials used. Defects such as pipe reproduce themselves under similar conditions of manufacture; but many defects in steel were of a casual nature. Such routine work would much be facilitated if the necessity for photographing could be avoided, and fluorescent screens could be used; for inspection work in particular a simple screen method would be preferable. At present this did not appear to be possible, and the appliances were too costly and delicate. A point to be borne in mind was that the X-ray examination did not magnify the defects to be looked for, which had to be visible to the naked eye. On

the other hand, the method gave us information about the atomic and crystalline structure, and might be useful in the investigation of allotropy as also in metallurgical analysis.

The third paper, on "The Radiographic Examination of Carbon Electrodes Used in Electric Steel-making Furnaces," referred to the troubles caused by the fracture of the electrodes, which may spoil a whole cast of steel. The carbons, up to 20 inches diameter, are made of amorphous carbon or of graphite; the former, which gave most trouble, were more heterogeneous than graphite and more suitable for radiography, it was stated, and the paper dealt particularly with amorphous carbon electrodes. In the electrode manufacture, retort carbon, anthracite or petroleum coke or mixtures of them are crushed and mixed with pitch and tar to be moulded under pressure, in cylinders or by extrusion, and then baked. The paper contains particulars as to diameter, ash contents (generally about 4 per cent, 15.8 per cent in one case), actual and apparent gravity (ranging from 1.8 to 2.2 and 1.47 to 1.65), and porosity (3.5 per cent to 33.8 per cent, the carbon mentioned rich in ashes having a porosity of 11 per cent), of eight samples from different firms. Sections, 1 inch in thickness, were examined by Messrs. H. W. Cox and Co., with a Coolidge tube, 6-inch spark gap, 20 inches distance anode to plate, 2 milliamperes and exposures of 1 minute, which might have been reduced. Positives were afterwards prepared from the negatives in the Hecla Works of Messrs. Hadfield, and these positives are much clearer, it was stated, than the negatives reproduced in the paper. In one set of experiments small boxes of the materials used, retort carbon, pitch, and anthracite were radiographed together with the respective electrodes; those pictures afforded little further information, probably because the baking altered the raw materials too much. The information gained as to the structure was considered valuable, though the interpretation of the radiographs did not appear to be easy. A coarse structure was not found detrimental to good behavior, *i.e.*, freedom from fracture; the specimen richest in ashes [a point to which attention is not drawn in the paper, we should say] proved the best electrode; it was of a very coarse structure, but the worst electrode was also very coarse, and the electrode of finest grain proved only of average quality. A systematic investigation, the authors stated, of electrodes of various compositions, baked at different temperatures, etc., appeared desirable and might explain the appearance in the radiographs of some very dark grains, possibly grains in the process of assimilation. Some graphite electrodes gave radiographs devoid of any structure; in one of them a crack was shown.

The fourth paper from the Hadfield Research Laboratory was on "A Method of Testing an X-Ray Tube for Definition." We shall later notice this paper together with others of a similar nature.

In a short note on "The Detection of Hair Cracks in Steel by X-Rays," Lieutenant-Colonel C. F. Jenkin stated that he had been persuaded to try whether it would be possible to detect hair cracks which had given considerable trouble in the crank-shafts of aero engines, though there seemed to be little likelihood of success. The samples had been examined by the experts who were pushing the process. The samples were cut from crank-shafts with large and relatively obvious flaws; but no trace of defects was shown by the X-rays. One sample, about 2 cm. thick, was cracked right through the thickness for a length of 6 cm.; but the radiograph gave no indication of the crack. If such large flaws were undetectable by the X-rays, the method was obviously useless for finding hair cracks, Colonel Jenkin remarked, adding that he did not follow Professor Bragg's arguments concerning the explanation of the detection of minute differences in the sheet thickness by means of the rays.

RADIOMETALLOGRAPHY.

The appliances used at Creusot are supplied by Messrs. Pilon, and further information on these apparatus and their use was given in a paper on "Radiometallography" by Mr. Hector Pilon and Mr. Geoffrey Pearce, of Messrs. Watson and Sons, Sunic House, Kingsway. The paper was read by Mr. Pearce, who stated that they had been able actually to penetrate steel in thicknesses up to 55 millimeters; with greater thickness the exposures became too long.

Under similar conditions, the same energy input, same potential and current, same distance, etc., a single block of a metal requiring an exposure of 30 seconds for a thickness of 15 millimeters, would require 250, 2,000, 3,500, 4,800, 6,500 seconds for thicknesses of 25, 40, 45, 50, 55 millimeters; thus a few millimeters made a great difference. In metal examination potentials of more than 100,000 volts were frequently employed, and for the present further perfection of the apparatus and photographic methods seemed to be the chief problem. For high penetration induction coils yielding 6 milliamperes at 150,000 volts with a spark gap of 30 centimeters seemed to be the most suitable; under 120,000 volts, 4 milliamperes were sufficient. The mercury-jet interrupters were better worked with hydrogen than with coal gas, especially for heavy currents. Where high generation was not essential, transformer and rotating rectifier-discs, the latter for 106,000 volts were used; in other cases either two valve tubes or one kenotron were recommended.

As regards the photographic side, reinforcement of the effect and elimination of all superfluous rays had chiefly to be studied. With the aid of one intensifying screen the degree of intensification could be raised 15 times; by placing the photographic film between two screens, they had determined differences in thickness of 0.1 millimeter through 45 millimeters of steel. Another advantage secured by these means was that the grain of the crystals in the intensifier—a feature we mentioned last week—was suppressed on the plate; the uneven nature of the crystals created a uniform field. Excellent results had been obtained with films sensitized on both sides. The film had the distinct advantage over the plate that it was flexible.

Fig. 1, annexed, is a reproduction of a radiograph of the entire cylinder of an aeroplane motor, which was obtained by placing four films inside the cylinder; the picture is a positive and the dark parts indicate greater wall thickness. The film could also be mounted in the following way: A base was formed of some polished or silvered metal; on this surface the reinforcing screen was placed, the phosphorescent metal on the top so as to be in contact with the film itself resting on it; on the film the second screen was laid, and on this screen finally the specimen was placed. In order to shut out stray radiations, the specimen was all surrounded with lead, 5 millimeters in thickness. When the specimen was irregular in shape, very fine lead shot was used, which also covered the photographic plate to a depth of at least 15 millimeters or twenty millimeters. This shot should, of course, not be allowed to get between the specimen and the plate, and to prevent that, the specimen was embedded in transparent wax (or plasticine), the wax being trimmed off so that the object rested properly on the plate, on which the lead shot could then be piled; the photographic plate itself was placed over a sheet of lead. Mr. Pearce exhibited a radiograph of a jagged piece of ore-bearing rock obtained in this way, an application of X-rays which deserves attention. That the observation of these precautions repaid itself was evidenced by the radiograph of the base of a 75 millimeter shell; this base looked quite uniform, but there was a faint white spot near the center, marking an invisible weakness in the metal which the pressure test had not revealed.

Mr. Pearce then explained with the aid of slides the arrangements adopted for the protection of the operator. In Messrs. Schneider's works at Harfleur (near Le Hâvre) the operator stood in a cabin, the walls of which were lined with 3 millimeters of lead, safe from the radiations which would spread through the whole room, but able to watch the X-ray bulb through 10 millimeters of anti-X-ray glass or with the aid of small lateral windows and mirrors. When working at more than 80,000 volts, a lead shutter was pulled down in front of the window, or the bulb was placed within a lead-lined box, a mirror being again used for watching the operations; this was the arrangement made for the examination of carbon electrodes and brushes by the Compagnie de Charbons de Nanterre.

We reproduce some of the other interesting slides shown by Mr. Pearce. Though neither the atomic weights of iron (56.8) and nickel (58.7), nor the densities (iron 7.88, nickel 8.9) differ much, Fig. 2 marks strong differences in the shadow depth of this radiograph; the specimen was prepared by embedding a nickel core in iron and planing the two metals down to the same thickness. In an aluminum gear case a defect had been stopped by aid of solder; the flaw came out as a dark spot. Fig. 3 shows the two halves of the bearing of an aeroplane motor, consisting of steel lined with white metal, the latter being held in position by the holes made in the steel; these holes are round, but appear elliptical and rather diffused in the one diagram because the radiation was not normal to the surface. The feature to which Mr. Pearce drew attention is, however, the streaking of this diagram; the streaks were not due to any want of surface finish, but to a faulty composition of the white metal. The carburettor of an aeroplane motor, shown in Fig. 4, was defective in operation. We are not sure that we can trace the defect in the petrol-feed canal which the photograph was said to reveal; but the radiograph, taken with an exposure of only 2 seconds and with the carburettor at the large distance of 125 centimeters from the target (in order to avoid distortion) is certainly a remarkable exemplification of the possibilities of stereoscopic radiography. Mr. Pearce mentioned that they had taken radiographs of the internal parts of an explosive body, 25 centimeters in diameter, made of steel, 12 millimeters thick, and had often been called upon to examine shells, fuses and torpedoes, by means of X-rays. The radiograph of the current distributor of the magneto of an aeroplane motor, Fig. 5, is again remarkable though we are afraid that our readers will not be able to distinguish the segments of the commutator, visible on the original, nor the exact nature of the defective contact which was located by the X-rays, and which is marked by an arrow in Fig. 5.

On behalf of Major J. Hall-Edwards, F.R.S.E., Professor Thomas Turner, of Birmingham, then exhibited some striking radiographs of aluminum castings, mentioning that experiments on brass and other alloys were being proceeded with. We hope to reproduce some of these radiographs on an early occasion.

X-RAY EXAMINATION OF AIR-CRAFT TIMBER.

What X-rays can do in the examination of air-craft woodwork, where the choice of unsuitable material, oversight, carelessness or the concealment of apparently slight mistakes may lead to obscure and fatal accidents, was very forcibly demonstrated in a paper by Captain R. Knox, M.D. (hon. secretary of the Röntgen Society), and Major G. W. C. Kaye, R.A.F., D.Sc., on "The Examination of Aircraft Timber by X-Rays." About the middle of 1918, Major Kaye stated, the Aeronautical Inspection Department decided to utilize X-rays for timber inspection. The equipment of the Cancer Hospital was used, and the results were very encour-

aging. Owing to the severe pressure the method had not yet reached the stage of commercial application at the time of the armistice, but the remaining problems were chiefly of equipment, portability and similar matters. Expressing their great indebtedness to Lieutenant Hudson-Davies and also to Mr. G. F. Westlake, Dr. Kaye explained that they had from the outset recognized the need of rapid visual examination by fluorescent screens, reserving photography for recording cases which the screen had shown to be of interest. As all woods were transparent to X-rays, soft tubes, and spark gaps of 1 inch or 2 inches were sufficient; the output of soft tubes being small, and fluorescent screens requiring excitation by rather hard rays, however, rays as hard as feasible, transformers and Coolidge tubes for 15 milliamperes were used in this testing.

Examinations were made both of the material in the rough condition and of the assembled parts. In aeronautical timber the chief defects to be looked for were spiral grain (in spruce and its substitutes), hidden knots, resin pockets, compression shakes, incipient decay, grub holes, and very light woods. As regards differences in density, due to knots, resin, grub holes, etc., no difficulty was experienced; the other defects were more difficult to detect in thick specimens. The rays chiefly brought out the differences in density between the light spring wood and the denser summer growth, *i.e.*, the annual rings; practically that knowledge was useful only in marking localized hard grain which was objectionable for aircraft purposes. In a radiograph of silver spruce, taken tangentially to the rings, the grain-effect was rope-like, the curious criss-cross effect being due to the presence of "figure" caused by the elongated depression on the annual rings repeated from year to year. Other radiographs exhibited exemplified the slant of the fiber and the glue-joints. On the whole, however, the X-rays did not tell the expert much more as to the timber and semi-finished parts than he could discover by visual inspection; but experts were rare, and semi-skilled inspection would be facilitated by the method.

Passing to the examination of finished and assembled parts, Dr. Kaye remarked that the method was particularly useful for the study of parts, not made of solid wood, but constructed on the laminated or box principle. That construction had become necessary when the supply of high-grade timber had been endangered; smaller timber could be utilized, but the difficulties of inspection were much increased. With that construction defects could be concealed, and unscrupulous and careless workmen were aware of the fact. Notices had been displayed in aircraft factories: "A concealed mistake may cost a brave man his life." In spite of grave difficulties of labor and material, British aeroplanes were superior both in quality and numbers to those of any other nation. But there was a tendency to hide mistakes, the grave nature of which was underrated, and the vigilance of the inspectors had prevented many accidents. In most of the important parts, main-plane wing spars (from end to end of each wing); compression struts (between the two spars of a wing), interplane struts; and longerons, cross-struts and engine bearers (making up the fuselage), the composite construction was permissible. But the strut or spar was completely covered with fabric, veneer or ply wood, and visual inspection was ineffective, unless the inspector could manage to stand over the job all the time.

We select a few of the characteristic radiographs exhibited. Fig. 6 shows the end of a hollow box-strut; the internal strengthening block was badly fitted, each of the screws had split the wood, and the work was altogether discreditable and insecure. Poor workmanship is also manifest in the cutting of the internal strengthening block of the hollow main-wing spar of Fig. 7. The side view of a hollow aileron spar showed the

spar to consist of two halves glued together down the center after the sides had been spindled out; the two halves of the block should register accurately and the sides should be equally thick. In reducing the glued spar to finish dimensions workmen were, however, apt, Dr. Kaye explained, to plane away more wood on one side than on the other, thus reducing the strength.

In some other photographs (not reproduced) the X-rays at once revealed that the halves, which should consist of the same wood, had been made of different materials. The laminated spar, shown in front and side view in Fig. 8, was made up of three laminæ glued together; the external appearance was excellent, but the X-rays disclosed large knots and a grub-hole in the middle layer which would have weakened the spar to a dangerous degree. Fig. 9 exemplifies another kind of reckless work. The wooden skid (top of photograph) had been cut off too short to fit into its socket; to make up the length a piece of packing B had been introduced into the space below. In a wing skid like the one shown this would not be a vital matter, but the same practice had been resorted to in interplane struts. The skid socket, Dr. Kaye added, was aluminum, in. thick, and the radiograph was taken with a current of 10 milliamperes and a spark gap of 8 inches. A similar case was more serious. The internal compression strut did not enter its steel socket (1/20 inch thick) properly and had left an empty space; externally nothing indicated a defect, but the effect of the bad fitting would be that under vibration the strut would gradually work its way into the bottom of the socket, and the straining wires would become slack. Other radiographs illustrate a common defect. When the holes for bolts, crossing parts to be assembled in various directions, are not carefully bored, two bolts may foul one another; the detection of one such fault led to the rejection of dozens of completely finished main-wing planes. The defective riveting and soldering of the end of a steel petrol tank of an aeroplane (Fig. 10) might have attracted notice; but other cases, which Major Kaye illustrated, rivets of a tank which had heads on the outside only (none inside), and cracks in split longerons, cleverly hidden by gluing a shaving over the sand-papered surface, would have escaped notice without the X-rays. The latter have also been of great assistance in tracing the causes of accidents.

In concluding our notice of the general discussion on "The Examination of Materials by X-Rays," held by the Faraday Society and the Röntgen Society on April 29, we pass to contributions affecting the photographic problems of X-ray examination, and we mention in the first instance the communication on "A Method of Testing an X-Ray Tube for Definition," from the Hadfield Research Laboratory in Sheffield, presented by Mr. J. Brooksbank, B.Sc., A.R.C.S. The focal spot, Mr. Brooksbank pointed out, is never a point, but occupies a certain area, and the shadow can hence not be very sharply defined. In metal work the selection of a tube of very fine focus would be of little use, since the effects of secondary radiation would mask the extreme sharpness of the shadow produced in the radiograph. Moreover, the life of a target was generally longer with larger focal spots. Definition must also be taken into account, and Mr. Brooksbank described how this could be effected. The size of the focal spot could sometimes be ascertained by visual inspection; but with hot cathode tubes that was almost impossible. The size of the pitted area of the target roughly indicated the size of the spot. Coolidge had obtained a radiograph of the spot by the pin-hole method. An idea of the definition could be obtained by taking a radiograph of a wire gauze of fine mesh (45 to the inch) at a distance of about 50 centimeters from the spot; the spacings of the wires were irregular, however, and with elliptical focal spots the shadows might be distinct in one direction, but

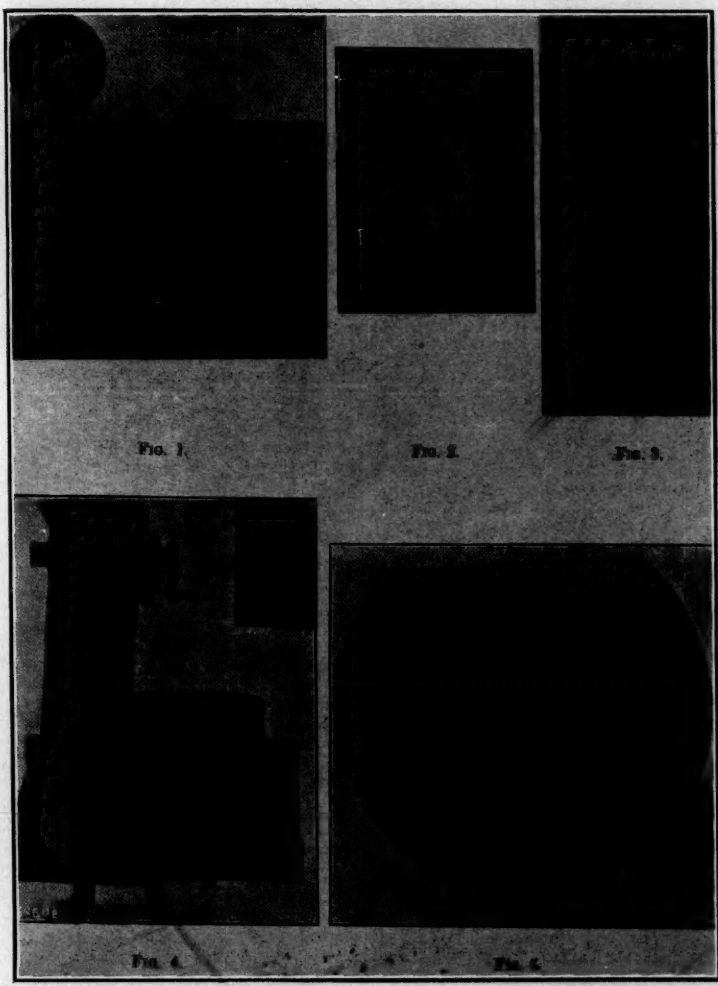


Fig. 1. Fig. 2. Fig. 3.

Fig. 4. Fig. 5.

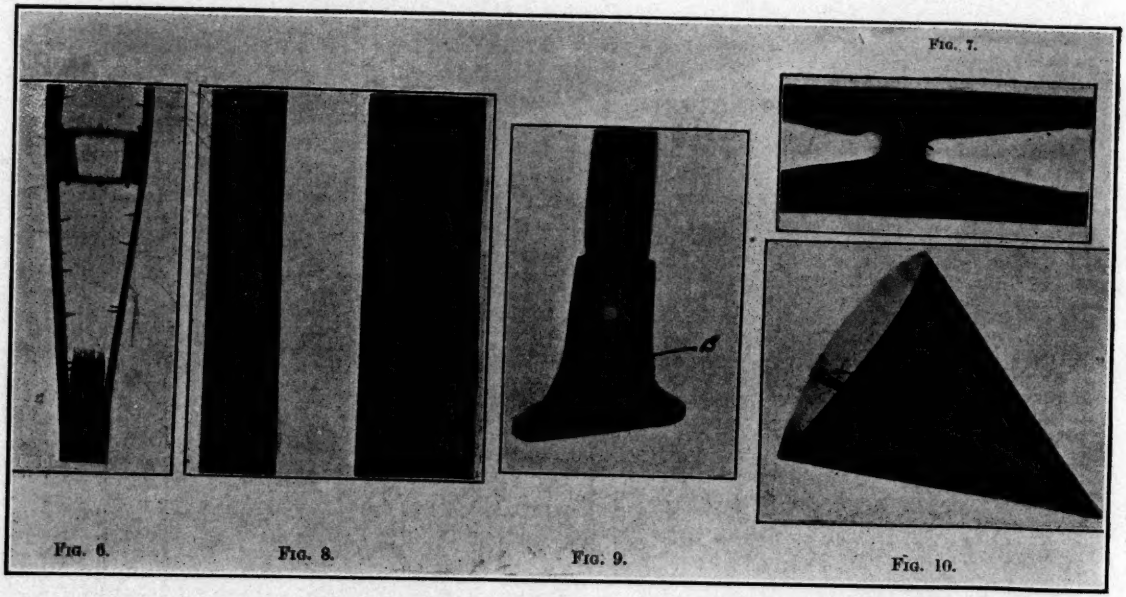


Fig. 6.

Fig. 8.

Fig. 9.

Fig. 7.

Fig. 10.

not at right angles to that direction. Moreover, sometimes reversal effects were observed. They had therefore used two uniform wires mounted parallel to one another in the same horizontal plane and to the plate; the distance between plate and focal spot was kept at 50 centimeters, and the wires were, in taking a series of radiographs, moved further and further away from the plate. As this distance increased, the shadows become less distinct until, in the "critical" position, the wires could not be seen on the radiograph; that critical distance was adopted as a measure of the definition of the tube.

In his research Mr. Brooksbank studied the shadows given by one wire or by two wires with two sources of X-rays, line sources and circular sources, and determined the intensity of the radiations produced when the distance of the plate from the wires was changed. As each wire received illumination both normally and from the right and left (as would be the case with any source of light of some area, not merely a point) the shadows were diffused, and the distance between the most intense shadows changed with the position of the wires. Comparative tests were made with a Nernst lamp and two pins. With a circular source the critical position was more difficult to decide than with a line source; yet the position could be determined within 2 centimeters or 3 centimeters; from these measurements the area of the focal spot could be deduced. For practical tests Mr. Brooksbank proposd to find by trial the critical position; he would then increase the distance of the wires from the plate slightly, and take radiographs; if the two shadows were separated by a strip of greater intensity than the shadows, the tube satisfied the requirements. Exposures of a few seconds would suffice; the definition would come out worst when the wires were at right angles to the line joining the target and cathode of the tube, and the examination might hence be made with the wires in that position.

Major C. E. S. Phillips then demonstrated how they had put this method to practical use in the War Office X-Ray Laboratory. The apparatus exhibited could hardly be more simple. There is a plate carrier into which the plate is pushed from the side; the plate is covered by a screen which is provided with a circular window. A ring frame attached to a stand holds the two wires, really fine needles, 0.2 millimeters apart; with the aid of a kind of a sliding cam the frame is fixed in one of three positions, at 15 centimeters, 10 centimeters, or 5 centimeters above the window. Radiographs are taken in these three positions, and the wire shadows will come out more or less sharp. Series of three radiographs were exhibited to exemplify how the apparatus is used for estimating the definition; with gas tubes, Major Phillips mentioned, the wires generally were not visible at all on the radiographs.

PHOTOGRAPHIC PLATES, EXPOSURE AND CONTRAST.

The two papers next read exemplified the nature of the photographic problems and the difficulties attending the interpretation of the radiographs. The first, on "The Behavior of Photographic Plates to X-Rays," by Messrs. O. Bloch, F.I.C., and F. F. Renwick, A.C.G.I., F.I.C., of the Ilford Research Laboratory, was presented by Mr. Renwick, who gave a brief account of researches, extending over several years, on X-rays and dry gelatin plates. When the mixed X-rays acted on a plate, he said, the relation between the amount of silver reduced by subsequent development and the quantity of radiation was represented by a curve of the kind of A, Fig. 11; the silver deposits being measured photometrically by determining their opacity logarithm or density ($\log_{10} O = D$); this quantity was plotted against the logarithm of the time of exposure to a

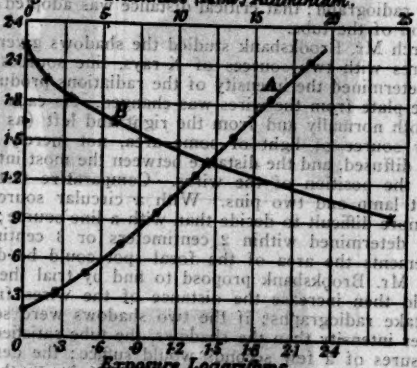


Fig.11.
Thickness (Mms) Aluminium.
0
5
10
15
20
25
2·4
2·1
1·8
1·5
1·2
·9
·6
·3
A
B
Silver Deposits (Densities).
0
·3
·6
·9
1·2
1·5
1·8
2·1
2·4
Exposure Logarithms.

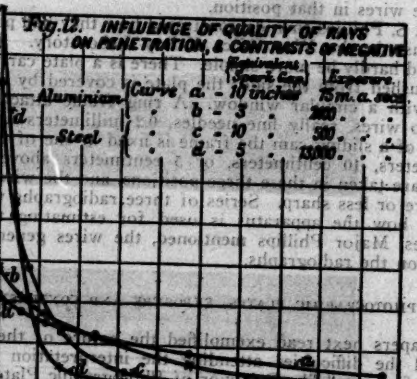


Fig.12. INFLUENCE OF QUALITY OF RAYS ON PENETRATION, & CONTRASTS OF NEGATIVE
(Rightmost Spark Gap)
Exposure.
Aluminium
Curve a. - 10 inches
15 m. a. secs.
b - 3 .
200 . . .
Steel
c - 10 .
500 . . .
d - 5 .
13000 . . .
Silver Deposits. (Densities).
2·7
2·4
2·1
1·8
1·5
1·2
·9
·6
·3
0
5
10
15
20

constant radiation. Such X-ray curves had a more pronounced foot (curved lower portion) than in ordinary photography; densities, moreover, were in this foot not proportional to the exposure, as was the case with light in the period of under-exposure. A satisfactory formula, independent of time of development, for expressing the sensitiveness of a plate to X-rays, such as Hurter and Driffield had given for light effect, had not yet been evolved; classification of plates relying on the straight line portion of curve (ignoring the foot) were undesirable as bearing little relation to practice, whilst speed numbers depending entirely upon the foot would possess a real value. Those points were not always heeded, however. When the rays first passed through some material before reaching the plate, selective absorption of the longer waves took place, and the thicker the specimen, the shorter would be the arriving wave-length; there was, moreover, scattering and transformation of the energy into characteristic radiation. The curve connecting the mass of silver reduced with the thickness of material penetrated differed hence from that found for varying the time of exposure to the same radiation. Curve B, Fig. 11, gave such a curve for aluminum. After a fair thickness had been penetrated the curve became inversely proportional to the thickness; to reach that shape early, however, *i.e.*, at moderate thickness, very short waves had to be adopted for metals of high atomic weight. Much depended upon the developer; on curves exhibited metolhydroquinone sodium-carbonate proved a faster developer than pyro-soda, but the increase in rapidity was not the same on different types of plates. The duration of the development did not affect the character of the curve.

The influence of the hardness of the rays was shown in Fig. 12 for a series of steps of aluminum (*a*, *b*) and of steel (*c*, *d*), *a* and *c* representing hard rays, *b* and *d* soft rays. The spark gaps used were of 10 inches, 5 inches, 3 inches, respectively, and the currents of 3 milliamperes, 6 milliamperes and 9 milliamperes; the exposures (in milliampere-seconds) are marked on the diagrams. The curves well indicated also that a far greater range of contrast could be obtained with steel than with aluminum; in the case of steel a wide range of intensity should evidently be considered to obtain the full characteristic curve; with the exposures used only the foot had been utilized. To get good contrasts with thick specimens of dense materials both the exposures to hard rays and the developments should be of long duration. Even with the hardest Coolidge tubes (spark gap 15 inches), however, and with very long exposures, 2 inches of steel seemed to be the limit of penetration, and they had hence tried to improve the sensitive materials, turning first to fluorescent intensifying screens. In Figs. 13 and 14 the effects of using commercial calcium tungstate screens were illustrated, the screen being in contact with a plate exposed to increasing doses of radiation; three different plates and various thicknesses of steel were used in Fig. 14. The shape of the curve varied with the ratio: sensitiveness to light to sensitiveness to X-rays, and it would be seen that, in Fig. 14, curve A (slow to light) was convex, B (fast) fairly straight, and C (very fast) concave to the ordinate. Fluorescent intensifier screens not only reduced the time of exposure, but they also increased the contrast, as Fig. 13 further showed. In normal X-ray work (and to a lesser degree also with intensifying screens) the silver deposits produced under the thicker parts of a dense object represented exposures falling within the foot of the curve. The tangent to that curve at any point was a measure of the degree of contrast at that point, and it was obviously not possible to secure good contrasts throughout a negative, unless the quantities of radiation were all sufficiently great to reach values well above those comprised with the shallow part of the foot. Failure to comply with this requirement was the chief reason of the difficulty of

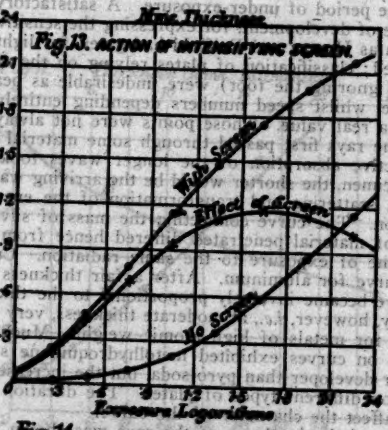
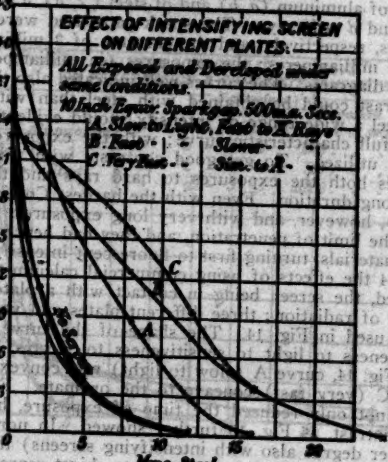


Fig. 13. ACTION OF INTENSIFYING SCREEN.
Mms. Thickness.
Silver Deposits (Densities)
With Screen
Effect of Screen
No Screen
Exposure Logarithms

Fig. 14.


EFFECT OF INTENSIFYING SCREEN ON DIFFERENT PLATES.
All Exposed and Developed under same Conditions.
10 Inch Equiv. Spark gap. 500 m.a. Secs.
A. Slow to Light, Fast to X Rays
B. Fast - - Slower - -
C. Very Fast - - Slow to X - -
Silver Deposits (Densities)
With Screen
No Screen
Mms. Steel.

bringing out very shallow defects in a thick piece of shell. Unfortunately, even the best commercial intensifying screens were granular and apt to mask fine detail in the radiogram. There was also a very great difficulty about securing good contact between plate and screen, and Mr. Renwick hence doubted the advisability of using separate fluorescent screens in cases where fine definition was essential. Though silver bromide was itself faintly fluorescent to X-rays, there seemed to be little prospect, so far, of making ordinary silver bromide dry plates much more sensitive. Some plates contained fluorescent substances or materials emitting secondary rays under very penetrating X-rays; most of these substances were either injurious to the silver bromide, or were difficult to incorporate in the emulsion. Mr. Renwick thought, however, that success might be achieved.

Dr. R. E. Slade, of the British Photographic Research Association, hardly did himself justice in his paper on "Contrast and Exposure in X-Ray Photography Through Metals." Considering the efficiency of the photographic plate, he said, that the experiments of Barkla and Martyn (1913) were the only ones available showing the relation between photographic effects and wave-length of the radiation (characteristic K radiations of metals), and their curves were not very accurate. Dr. Slade did not add, however, that his very interesting conclusions, which appeared to be little more than mathematical deductions, were in agreement with investigations by Professor Bragg—who had drawn attention to Dr. Slade's paper—and others. The developed negative, Dr. Slade pointed out, left the glass covered with a coating of gelatin containing finely-divided silver. Barkla's curve (Fig. 16) indicated that the absorption due to the silver bromide increased with decreasing wave-length first in a small step, probably due to the bromide, and then in a larger step, due to the silver. If j_0, j_t and j_s represented respectively the intensities of the incident, transmitted and absorbed rays, the ratio j_t / j_0 was the transparency (and its reciprocal the opacity), and Dr. Slade showed that when the rays entered the film directly (without having first passed through metal), $j_t = j_0 . 10^{-D}$ where D was the density of the silver in the film, in the sense of Hurter and Driffield (1890), who meant by density the number of particles of a material spread over unit area, which was a measure of the chemical work done by the light. The density varied with the exposure E (the product of intensity and time) according to $D = A + B \log. E$, where A and B were constants. The two curves, Fig. 17, exemplified the relation between D and log. E for exposures of 8 minutes and 16 minutes. Both were practically straight lines between *b* and *c*; between *a* and *b* was the region of under-exposure, between *c* and *d* the period of over-exposure, and at *c* the exposure would, on an ordinary plate, be about 300 times as long as that at *b*. These curves held in the first instance for ordinary light; Tugman (1915) and Hodgson (1917) had proved that the relation between D and E was the same for X-rays. As it was almost impossible to print from an over-exposed X-ray negative, most X-ray photographs were taken on the under-exposure portion of the curve.

Dr. Slade then considered the case when the X-rays first traversed a thickness of *d* centimeters of a metal of absorption coefficient λ—this designation of the absorption coefficient by λ in problems affecting wave-length is regrettable, but common practice—before entering the film of thickness *t* and absorption coefficient λ_1 (silver bromide). Both λ and λ_1 varied with the wave length; but except at points where there was selective absorption, λ would be equal $a\,\lambda_1$ (where *a* was a constant), and in that case the equation $\lambda d = 1$ would hold. That meant that the photographic effect for a metal thickness of 2 centimeters would be maximum

if $\lambda = 0.5$, and with most metals the radiations to be used for examination should hence be exceedingly hard (*i.e.*, of short wave-length). The remarkable change of the absorption coefficient λ with wave-length was exemplified by the following table, which gives the λ for aluminum and iron, and for iron also by Fig. 16:—

Wave Length in 10^{-8} *Cm.*	λ *Aluminum.*	λ *Iron.*
1.95	238	518
1.80	192	527
1.66	140	2460
1.55	128	2100
1.45	106	1740
0.72	8.3	262
0.56	6.7	136
0.50	4.3	86
0.48	3.3	66

In order to attain the greatest contrast, that is, the greatest density difference $D_1 - D_2$, where D_2 marked the density at any spot where the rays had passed wholly through metal, and D_1 at a spot where they had traversed a blowhole, the exposure should be on the correct exposure portion between *b* and *c*, Fig. 17. But with the thick emulsions of X-ray plates the negatives would then be far too dark for printing, and the top of the under-exposure portion should hence be utilized. Since, further, the absorption λ was great for long waves (soft rays), soft rays would give better contrasts; yet we had to use hard rays to shorten the exposures, and Dr. Slade showed that the contrasts were sufficiently great also with hard rays. Finally Dr. Slade referred in particular to the case of iron which [compare the λ curve of Fig. 16 and the table] had very high absorption values for wave-lengths greater than 0.5×10^{-8} cm., thus requiring long exposures. Yet —thickness differences of 0.005 cm. should be quite perceptible, especially, *e.g.*, with rays like the K radiation of nickel, 1.66×10^{-8} cm. As, however, nickel anti-cathodes were not very suitable for photography through iron, anti-cathodes of tungsten or platinum and wave-length of 0.3 cm. or 0.45×10^{-8} cm. were preferable; large spark gaps would be required. In the case of tungsten the K radiation (the only one which mattered for these purposes) had with 68,500 volts a wave-length of 0.18×10^{-8} cm., which became reduced to 0.12 of the same unit at 100,000 volts, thus being fairly steady. In the case of molybdenum the wave-lengths fluctuated very much more.

The important point in these conclusions was that the contrast in photography through, say, 1 cm. of iron, did not depend upon the absolute thickness of the iron, but that the effect was almost entirely due to the hardest rays, though it would be greater with relatively soft rays. That seemed contrary to experience. The explanation was this, Dr. Slade mentioned. Supposing there was a blow hole of 1 mm. in 1 cm. of iron; a good contrast could easily be obtained. If that same bubble were in a specimen 6 inches in thickness, the same contrast could, with the same tube voltage, be obtained by increasing the exposure many thousand times, the function being exponential. In practice we used harder rays to reduce the exposure period; but the contrast was then very much less distinct. We do not know how far these arguments are influenced by the fundamental assumption that the photographic effect depends upon the product: intensity multiplied by time of exposure [milliamperes by seconds), and not upon each of the two factors independently, or that, in other words,

Fig. 15.

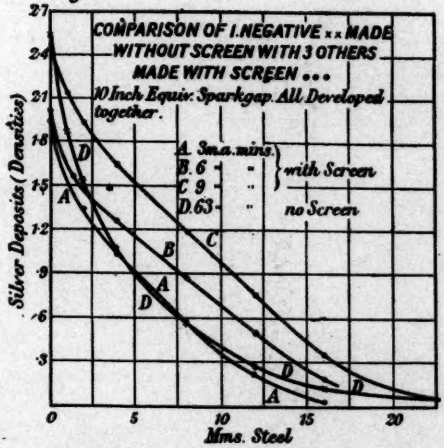

COMPARISON OF I. NEGATIVE x x MADE WITHOUT SCREEN WITH 3 OTHERS MADE WITH SCREEN ...
10 Inch Equiv. Sparkgap. All Developed together.
A 5m.a.mins.
B 6 - "
C 9 - "
D 63 - "
with Screen
no Screen
Silver Deposits (Densities)
Mms. Steel

Fig. 16.

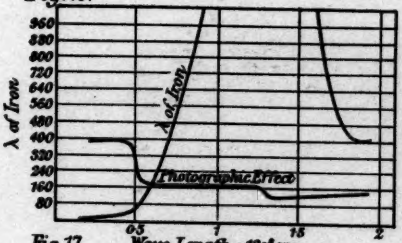
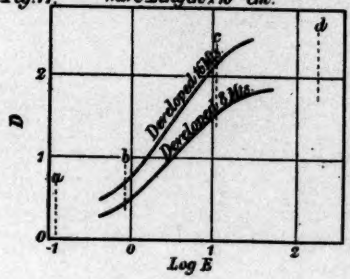


Fig. 17.



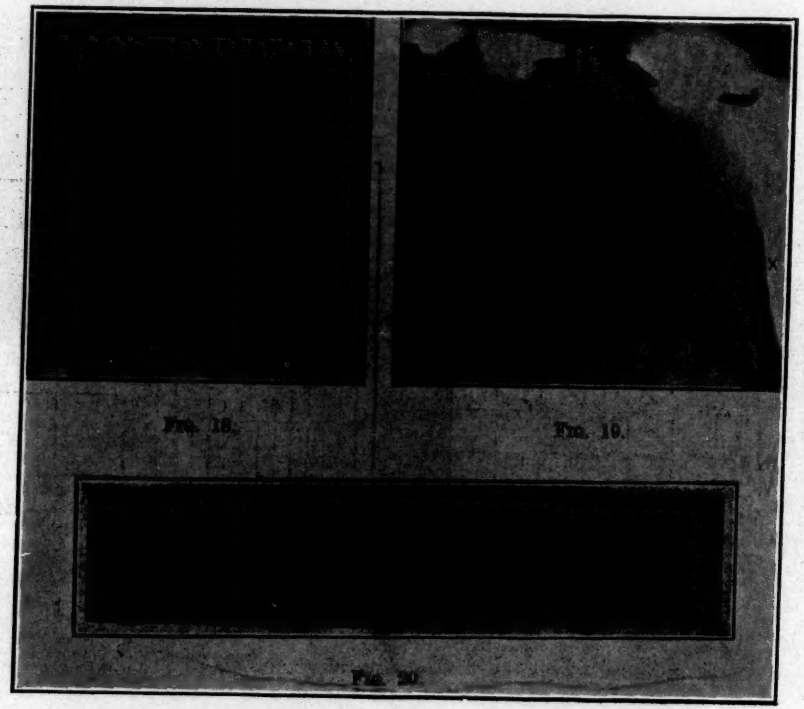


Fig. 18.

Fig. 19.

Fig. 20

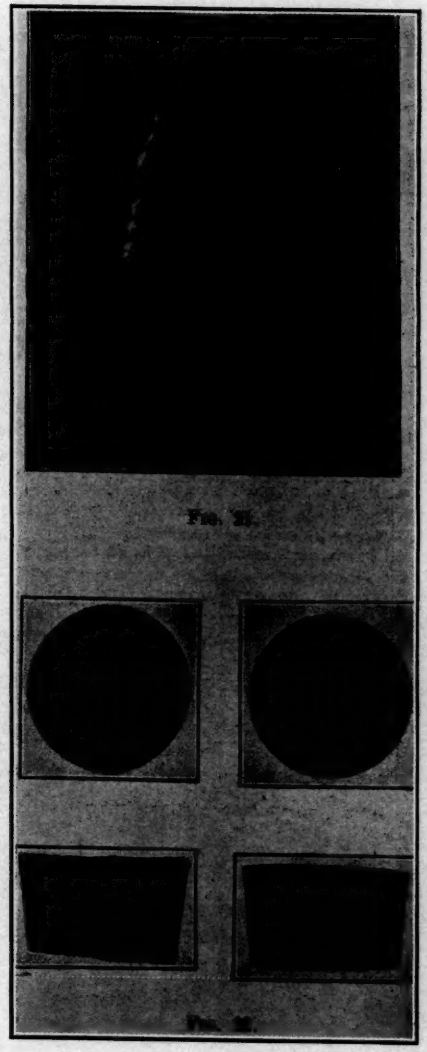


FIG. 23.

weak intensity with long exposure has the same effect as strong intensity with short exposure. Photographers accept that assumption—with reservations—and like them, X-ray workers rely on photographic densitometer tests. But the principle is certainly questionable, especially as regards X-rays. The rays are not homogeneous; they probably fluctuate in hardness from moment to moment and with the hardness varies the scattering which plays an important, yet quantitatively unknown, part. Dr. Slade considers that possible deviations from the milliampere-second rule would hardly affect his conclusions. Mr. Renwick referred to this difficulty in the beginning of his paper, but he expressed exposures in the customary way in milliampere-seconds.

In the general discussion Mr. A. A. Campbell Swinton, F.R.S., remarked that the X-ray bulb problem should be tackled on engineering lines. He did not wish to be limited to milliamperes, but wanted kilowatts. That was not an impossibility. In radiotelegraphy, valves had been used as detectors; now they served as oscillators. The trouble with glass tubes was that strong currents melted them; with steel tubes the occluded gas gave trouble, unless the whole tube were evacuated while red hot. But the interior of the metal tube might be enameled as in Gaede pumps; such tubes, of 2 feet or 3 feet diameter, for 10 kw. or 15 kw., would not cost so very much, and we did not know what they might be able to do. Referring to this, Captain Kaye stated afterwards that Coolidge had, in his especially-cooled tubes, gone up to 14 kw. (20 h.p.) before the war, but the war had forced other work upon him; metal tubes had been introduced by O. Lodge 20 years ago, and all-metal tubes provided with porcelain insulators had been used on the continent by Zehnder and by Siegbahn. Most experimenters seemed, however, to have dropped the metal tube eventually. Captain H. G. Jackson, for some time Ordnance Inspector at Sheffield, said they wanted some means for rapidly examining heavy ordnance forgings made of nickel-chrome steel. That steel showed typical flaws which so far they could only discover during turning; to make fairly sure of having their parts of the required strength, they had to allow for a very large margin of safety. Hence some means for rapidly testing assembled parts would also be most valuable. Mr. S. A. Pollock, of the Postal Department, remarked that the Post Office was very much interested in the possibilities of X-rays; there were many baffling problems—the study of the corrosion and uniformity of cable sheath of lead, of their steel armoring, and of their insulation, among others—which the X-ray tube could help to attack, and they were going to try this method; it had already proved useful in examining gutta-percha for adulterations.

The few photographs, which we finally add, will further exemplify the valuable services that the X-rays can render to the engineer and metallurgist. Figs. 18, 19 and 20 explain the examination by Mr. H. S. Rawdon, of the United States Bureau of Standards, of two pieces of steel, one suspected of being "flaky"; the point was mentioned by Sir Robert Hadfield in his introduction. The latter specimen was cut transversely out of a finished gun forging, of a steel containing 0.37 per cent carbon, 0.01 chromium, 2.85 nickel; a very similar specimen gave a uniformly grey radiograph, the suspected specimen, 3/8-inch thick, showed the flake visible in the line XX. When the specimen was sawn open along this line and broken, the large flake of Fig. 20 (an ordinary photograph) became visible. A similar, very striking case, is illustrated in Figs. 21 and 22, which Professor Bragg exhibited in the course of his address. The photograph Fig. 21 shows a bad flaw in a 5/8-inch turbine casting. The black ring marks the spot where a button was cut out of the specimen. This button, 3/16-inch thick, was photographed in the ordinary way in four views (Fig. 22). The top and bottom of the button do not display any

flaw, but in the two other views, taken from opposite sides, the flaw is very distinct. These X-ray photographs were taken by Dr. Coolidge in the Research Laboratories of the General Electric Company.

Fig 23, from the same source, refers to the improvement of high-conductivity copper effected by boron suboxide. Cast copper is frequently full of pores and blowholes; ordinary deoxidizers added to the copper remove the gases, but alloy with the metal and lower its electric conductivity; the boron suboxide of O. Weintraub deoxidizes the copper without combining with it, and tons of copper are now cast by the General Electric Company with boron. Fig. 23 shows the "unboronized" copper. The radiograph of the "boronized" copper, which Professor Bragg placed next to our photograph, was merely a spotless grey square. Professor Bragg further showed radiographs of some good and some bad welds; they were quite sufficiently plain to let the operator recognize the success or failure of his work, but they might not come out well in our reproduction.

Radiographs of welds and of other specimens and X-ray apparatus, etc., we should not omit to mention, were also exhibited by the British Thomson-Houston Company, by Messrs. H. Cox & Co., and by Messrs. Newton and Wright. One of the exhibits of Messrs. Watson & Sons, to which we have already referred, was their stereo-fluoroscope, an attachment to X-ray outfits, especially designed for the examination of materials and general objects the structure of which appears in stereoscopic relief.—"Engineering."

GERMAN TONNAGE POSITION.

There is as yet no visible sign of a move on the part of the German shipping companies. Reports abound, including one of an amalgamation of the Hamburg American Company and the North German Lloyd, with Herr Heineken as managing director. The Germans say they have lost over 4,000,000 tons out of a total of 4,935,909 tons, and that what is left to them is insufficient for the Baltic trade alone. In any case, for the purpose of international competition, they are and will be for some time to come without ships. They should not, however, be without funds, seeing that the direct financial loss arising from the surrender of their fleets does not fall on them, but on the German Government. Their financial position, however, is declared to be considerably prejudiced by their having to repay their liabilities to the Dutch shipping mortgage banks, which at the present rate of exchange will mean a heavy burden. The amount of this indebtedness can only be surmised, and we are inclined to think it is not great. The German banks were generous supporters of the shipping companies before the war, and their method of furnishing funds was sufficiently satisfactory to render it unnecessary for the latter to look elsewhere for financial help. The banks advanced the money required to build the ships and received the amounts usually written off for depreciation. But whether armed with ample funds or not, and notwithstanding the really terrible account of the condition of the population in Germany described in the parliamentary paper just issued (Cd. 280), the German companies are, there is reason to believe, now busy making preparations in Holland and Scandinavia both in the form of chartering and in acquiring interests in steamship companies.—"Shipbuilding and Shipping Record."

LUBRICATING SYSTEMS FOR GEARED TURBINES.

Probably the most important detail in the laying out of a geared turbine installation is the provision of a simple and reliable oiling system. So vital is the question of lubrication to the operation of the machinery, that too much attention cannot be given to the design and lay-out of the oiling gear fitted. The pressure system of lubrication is always adopted in modern turbine installations, and, in addition to providing for the lubrication of the main bearings of the turbines themselves, provision must also be made for the efficient lubrication of the gears, this comprising the lubrication of the various bearings supporting the pinion shafts and the gear-wheel shafts, in addition to the lubrication of the teeth at their point of contact. This latter is usually performed by a series of jets of oil, delivered from pipes mounted near the point of contact of the pinion and gear teeth, the jets being delivered right on to the point of contact, and in the direction of motion of the teeth, so that there is always a film of lubricant preventing the actual metallic contact of the teeth of the pinion and of the gear. In fact, it may be said that the problem of efficient turbine lubrication consists of the provision and the maintenance of a film of oil at every point where two metallic surfaces move the one over the other.

Two systems of lubrication have been devised, the first in which separate oil pumps are provided, usually in duplicate, and the second, in which the pumps are direct driven from one of the shafts of the gearing, in the case of double-reduction gearing the intermediate gear shaft being employed for this purpose. In both systems the lubricant is delivered to a gravity tank, situated as high as possible above the machinery, 20 feet being considered a minimum figure in this connection, the oil to the bearings and the gears being supplied from this tank by gravity, some form of float valve being provided to automatically govern the delivery from the pumps. In the case of vessels where there is insufficient head-room to fit the gravity tank at a proper height, a pressure oiling system has to be adopted, and special precautions have to be provided to ensure an uninterrupted supply. The overhead gravity tank is usually provided with three strainers, having a successively finer mesh, it being a matter of supreme importance that the lubricant should be absolutely free from dirt before entering the bearings or the gears. In the event of the screens becoming choked, however, there must be no interruption of the service, and hence they are mounted in the gravity tank in large frames, so that the oil can flow over the top of the screens. Moreover, they can be readily removed for cleaning, and any dirt falling from the screen while they are being removed will be caught in the frames, and thus prevented from remaining in the oil. The outlet from the gravity tank to the machinery should be well above the bottom, so as to avoid drawing off any sediment; but a pipe should, of course, be provided at the bottom of the tank for drawing off this oil to a filter or a settling tank. The character of the oil in the bottom of the gravity tank should be regularly observed, so that the engineer on watch may be sure that no water is entering the system from any source.

With the pressure oiling system, as found on board torpedo-boat destroyers, it is still necessary to employ some form of strainer to filter the oil before delivery to the machinery. There is, however, a danger that these may, on becoming choked up, interrupt the service; or if the pumps are sufficiently powerful the strainers may be burst, thus letting dirt through. To avoid this, the strainers by-pass through a spring-loaded check valve, sometimes loaded to about ½ pound per square inch, so that with a slight increase of resistance of the strainers the oil will go via the by-pass, and the service will never be interrupted. As a further means of preventing the circulation of dirt with the lubricant, the suction

to the oil pumps is placed several inches above the bottom of the drain-oil tank, so that any dirt or emulsion in the oil which drains from the bearings and the gears into this tank may settle at the bottom, and not be drawn up and delivered again to the machinery. An additional suction is, however, employed at the bottom of the tank by means of which the dirty oil may be pumped through a filter, and to permit the complete emptying of the tank for cleaning purposes. This drain tank is located sufficiently low to ensure the oil draining freely to it from the machinery, the tank being as large as possible, with connecting pipes of ample size, so that, as far as possible, even with extreme rolling and pitching of the vessel, there will be no leakage of oil from the bearings. The oil pumps are placed near the drain tanks, and at as low a level as possible, in order to reduce the suction head to the least possible. A further detail which has also to be carefully considered is the provision of oil coolers, since the oil, on leaving the machinery, is often at a temperature considerably above that at which it was supplied, and any further rise on again passing through might lead to a considerable falling off in its lubricating properties. The oil coolers are usually arranged on the discharge side of the pumps, between the pumps and the gravity tank. The coolers are duplicated, so that while one set is in use the other may be cut out of service. The oil coolers should also be by-passed with a spring-loaded check valve, loaded to some amount greater than the resistance of the cooler, so that under no conditions can mis-handling of the valves cause interruption of the service.

Opinion amongst turbine designers is divided as to the relative merits of the oil pumps driven direct from the gear shaft, as compared with the independent pump. It is recognized that under circumstances when the vessel is maneuvering for a long time, the direct-driven pumps may not be capable of supplying a sufficient quantity of oil; it is therefore usual to install a small independent oil pump. Moreover, with the direct-driven pump it is certain that a larger quantity of oil is circulated than is actually necessary. The independent pumps, while lacking the extreme reliability of the direct-driven pumps, are, when properly controlled, able to deliver only just that quantity of oil needed by the system, and this, no doubt, will have much to do with increasing the life of the lubricant, as well as tending to simplify the filtering arrangements.—"Shipbuilding and Shipping Record."

SOME DEVELOPMENTS IN AIRCRAFT DESIGN AND APPLICATION DURING THE WAR.*

By the Right Hon. Lord Weir of Eastwood, P. C., Honorary Fellow.

(Abridged.)

Any attempt to review the progress or development of aviation during the war, and to confine such a review to the permissible limits of a paper, involves a mere indication of some of the more salient features of the development. Moreover, it is difficult to confine any such review entirely to the scientific or engineering aspect of the problem, on account of the peculiarly close association of the technique of construction with the technique of use. The war development of a technical product, such as an aeroplane, necessarily comprises the rapid embodiment of field experience in the design and production of *material*, and this compelling influence during the war largely governed the policy of design, supply and production.

In August, 1914, the British Air Services consisted of a naval wing and

*Paper read before the North-East Coast Institution of Engineers and Shipbuilders, July 10, 1919.

a military wing, the first controlled by the Admiralty, and the second by the War Office. The naval wing, or Royal Naval Air Service as it was termed, possessed a total of 93 machines, the military wing or Royal Flying Corps possessed a total of 179 machines. In October, 1918, just prior to the armistice, the Royal Air Force possessed over 22,000 effective machines.

For the first two years of the war, the supply organizations for aircraft were departments of the War Office and Admiralty, and no distinct technical departments existed. In January, 1917, the second Air Board, under the chairmanship of Viscount Cowdray, succeeded the original Air Board under Viscount Curzon, and was constituted with additional duties and responsibilities. The Board became responsible for the allocation of aeronautical supplies between the two flying services, and for the supervision of design of all aeronautical material, this latter responsibility being vested in the technical department of the Air Board under Brigadier-General Pitcher. Concurrently with this, the entire responsibility for supply and production of all aircraft *materiel* was handed over by the War Office and Admiralty to the Ministry of Munitions. Toward the end of 1917, a movement in favor of concentrating the entire administration of everything relating to war aviation in a single Government department crystallized in the constitution of the Air Ministry under a Secretary of State for Air, the naval and military air services being amalgamated to form the Royal Air Force in April, 1918.

The establishment of the Royal Air Force as an independent fighting force of the Crown has been thoroughly well justified, and the progress with regard to civil aviation in this country since the armistice is largely due to the existence of a single air authority. Concurrently with the institution of the Air Ministry, the necessity of placing design and supply under a single authority was recognized by the constitution, within the Ministry of Munitions, of the Aircraft Production Department, which assumed full responsibility for all questions of design, supply and production.

An appreciation of the progress made in the domain of supply and production can be obtained from the fact that the average monthly delivery of aeroplanes either from British or foreign sources to our flying service during the first twelve months of the war was 50 per month, while, during the last twelve months of the war, the average deliveries were 2,700 per month. The capacity of the facilities in this country for the production of aeroplanes at the date of the armistice was approximately 3,500 complete machines per month. To those associated with marine engineering, it may be of interest to state that the total horsepower of aero engines produced in the last twelve months of the war, approximated to 8,000,000 of brake horsepower, a figure quite comparable with the total horsepower of the marine engine output of the country.

It may be of interest to recite some of the difficulties encountered in this work, although perhaps the more important of these difficulties were inseperable from the industrial position of the country at the period when the effort towards expansion was made:—

1. The lack of highly-skilled labor, in particular that required for engine production, due to the almost complete absorption of such labor by other and earlier war enterprises.

2. The very high standard of material and workmanship involved so that safety might be ensured on the low permissible weight of the product.

3. The necessity of creating and building up entirely new manufacturing facilities and organizations.

4. The grave influence on production of modifications in design shown necessary by field experience, and the necessity for the rapid embodiment of these in the product.

5. The inability to take the fullest advantages of standardization, owing to the necessity of making continuous progress in design and performances of machines.

6. The extreme complexity and variety of the elements contributing to the provision and equipment of war aeroplanes.

For example, the provision of satisfactory timber was a continual difficulty—at times an actual menace to the whole development. The textile problem became very grave when the supplies of Russian flax were cut off, and we were compelled to develop additional sources in Ireland and in the Colonies. Acute difficulties were experienced in connection with the development of the chemicals required for dope manufacture. At other times, the supply of machine guns gave much anxiety, while the development of the synchronizing gear for these guns necessitated very urgent treatment.

The production of ball bearings involved the provision of new facilities on a colossal scale. The magneto supply involved the building up of an entirely new industry, while the manufacture of the numerous classes of instruments, cameras, radiators and other fittings in each case formed a problem by itself.

The solution of these problems from a production point of view constitutes an outstanding example of the enterprise, courage and ingenuity of British industry. Many mistakes were made, but most of the difficulties were solved and many valuable lessons have been learned. It is a matter of great regret that so many of these enterprises, built up for specific war requirements, cannot be maintained under peace conditions. The development of civil aviation will not, for many years, absorb even a fraction of the war facilities, and a large amount of waste cannot be avoided in the reduction of these industries to a peace-time basis.

The constitution in 1917 of the first Technical Department dealing with aircraft design represented one of the most valuable steps in advance of previous organization, and the work of this department very largely contributed to the position of technical supremacy held by this country at the close of the war. One of the factors contributing to this success was undoubtedly the adoption of a policy of giving ample freedom of opportunity to private designers, because in the development of a new art, such as aircraft design, any adherence to a single school of thought is dangerous, and the basis of design and experiment should be broadened as much as possible.

In the earlier days of the development the official Government designs of the Royal Aircraft Factory at Farnborough predominated, but the change in policy should not be taken to represent a reflection on the many valuable designs produced at Farnborough. These designs exercised a great influence on all future designs, while the meticulous care in the details, which was the feature of Farnborough practice, has been wholly useful and valuable in its general influence. To the British aircraft designers as a whole, and in particular to the pioneer designers and manufacturers, the greatest credit is due for their courage, skill and ingenuity.

Such is the briefest possible review of the political and administrative conditions under which the developments in war aviation have been carried out. In dealing with the salient features of progress and design two aspects have been separately treated—the aerodynamic aspect and the applicational aspect. As regards seaplanes it is not proposed to deal with their detail development, as this followed generally on the same lines as the aeroplanes with the special adaptations to meet marine conditions.

PART I.—AERODYNAMICAL ASPECT.

Loading.—The outstanding feature desired in war aeroplane performance was expressed generally as the maximum of speed and climb, and it was

soon perceived that this feature could be best achieved by a reduction of the weight carried per horsepower. The advance in other aerodynamic features such as wing section, reduction of air resistance, etc., was considerable, but could not be compared in importance with the reduction of the weight per horsepower.

At the beginning of the war, loadings were about 23 pounds per horsepower and 4 pounds per square foot of lifting surface; at the close of the war, nearly 7 pounds per horsepower, and 10 pounds per square foot. This is a remarkable result when it is considered that 7 pounds per horsepower represents the power loading of the total weight of the aeroplane, comprising the engine, its petrol and oil, the aeroplane itself, the pilot and all his fighting equipment. The rate of progress achieved in this development entailed a corresponding large demand on the skill of the pilot, but it was found that the pilot's skill always advanced rapidly as the demands upon it.

Wing Sections.—Wing sections steadily developed from the early sections with their hollow undersides and tops of almost circular camber, to the high efficiency sections of the present day with flat undersides bulged slightly downwards for the spars, and upper surfaces with a quick nose curvature, flattened top and easy run aft.

The illustration, Fig. 1, shows these differences fairly well. It may be noted as an interesting fact, that the Germans at no time made use of a high efficiency section such as the R. A. F. 15 shown.

Air Resistance.—No revolutionary advances have been made during the war in regard to the reduction of air resistance, but the general trend has been the more rigid application of previous knowledge; the conversion of piano wire or cable to streamline wires for main bracing is perhaps the most noteworthy feature. Until quite recently stream-line wires were not adopted by any other country than this, although for fast aeroplanes the gain is considerable—approaching 10 miles an hour on a machine with a speed of 110 miles per hour.

The fuselages were made of fairer shape, and pilots and accessories were more carefully enclosed and protected.

Stresses and Factors of Safety.—At the outbreak of hostilities very little was known of the magnitude of the forces which might occur in flight, and certain more or less arbitrary rules were used in determining the strength of the aeroplane. Many possible methods of failure were never considered, and in some cases it was only through the light shed by certain accidents that progress was made. Certain definite forms of failure which are now always considered and guarded against were only discovered after long and careful examination and analysis of accidents.

When an aeroplane is flying level at a constant speed the air loads acting vertically on the lifting surfaces (wings and tail) must, of course, be equal to the total weight of the aeroplane. Other conditions must be simultaneously fulfilled, but this is the primary one.

This air load on the wings is known as the normal or unit flight load and is the basis of all strength calculations. It will be clear that in order to accelerate the aeroplane, extra forces must be applied, to it, and so in many maneuvers through which the aeroplane is put, extra loads are thrown upon the structure.

These forces are measured in terms of the unit flight load, and their magnitudes are determined either by calculation or by experiment. Both methods are used, and the advance in knowledge on this question, during the war, has been one of the principal causes of the elimination of practically all accidents which may be genuinely attributed to structural failure, and the great reduction in the percentage weight of aeroplane structures. The experimental method of determining the values of these loads consisted in carrying an accelerometer on an aeroplane. This instrument

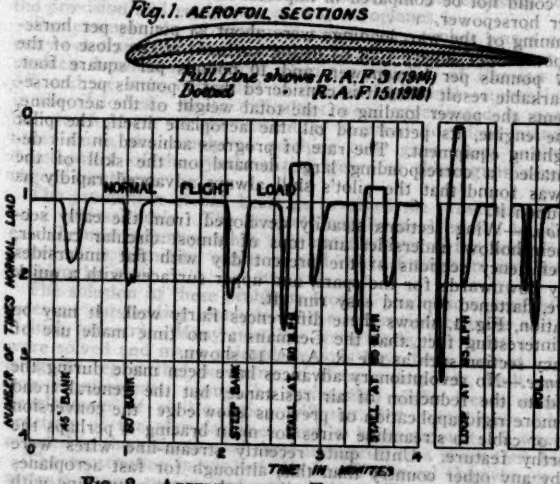


FIG. 2. ACCELEROMETER TESTS. FLIGHT LOADS B.E. 2C.

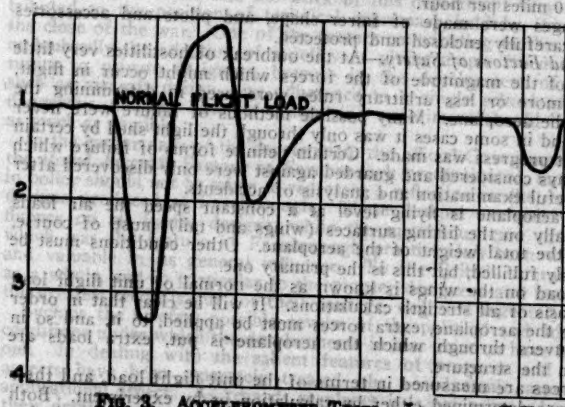


FIG. 3. ACCELEROMETER TESTS. LOADS ON B.E. 2C.

was self-recording and registered the amount of the accelerations given to the craft during various maneuvers. Developed by Professor Lindemann and Dr. Searle at the R. A. E. its value has been considerable. The illustrations (Figs. 2 and 3) were obtained from one of their autographic records, and these and the attached table will give some idea of the value of the loads which occur during aerial maneuvers. It must be understood that these loads are not the maxima which could occur, but only the maxima registered during the experiments.

Table of Loads.

Ordinary bumpy weather.	1½ to ⅓ normal load.
Spiral dive at 70 miles per hour.	2.8 times normal load.
In a mock fight between S.E. 5 A. and R.E. 8.	3 times normal load was common; at times this increased to nearly 4.

Until all the loads which can possibly occur on an aeroplane are known it is impossible to design an absolutely scientific structure, but considerable progress has been made during the war in this direction, and it is at least possible now to design a structure that will not break in the air except under certain conditions against which the pilot can be warned.

In all other branches of engineering the prevention of failure is obtained by the introduction of a factor of safety, so that the highest possible loading which can occur in the structure stresses the material to only a fraction of its ultimate stress.

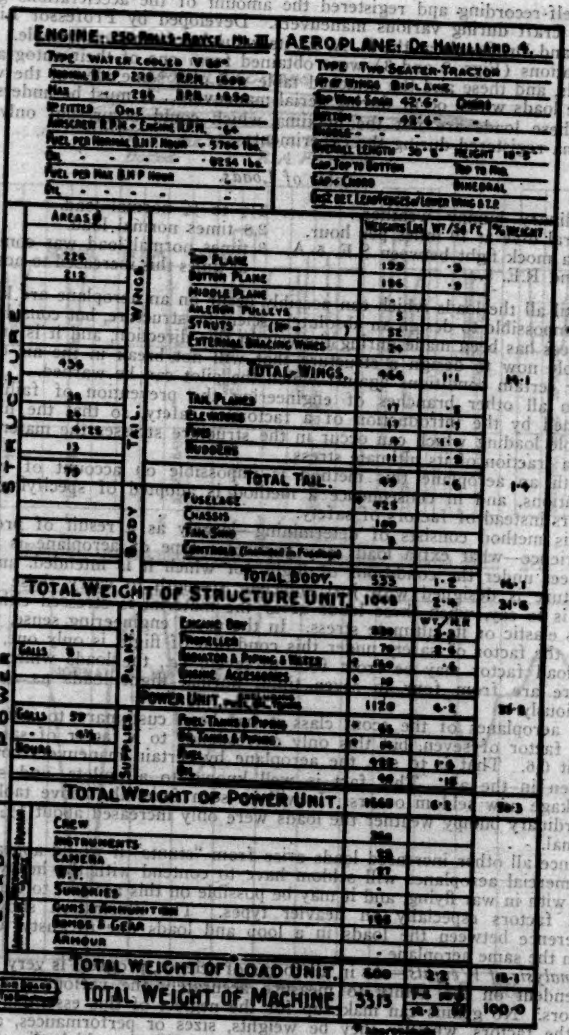
With an aeroplane this method is impossible on account of weight limitations, and in consequence a method is adopted of specifying load factors instead of factors of safety.

This method consists of determining—largely as a result of previous experience—what extra loads any particular type of aeroplane is likely to meet under the conditions of flight for which it is intended, and the structure is designed with just sufficient strength to carry these loads, that is to say, when these loads occur the material is stressed either up to its elastic or its ultimate stress. In the usual engineering sense, therefore, the factor of safety under this condition of flight is only one, while the load factor may be from four to seven, *i.e.*, the loads which cause failure are from four to seven times normal flight loads as specified previously.

In aeroplanes of the scout class it has been customary to ask for a load factor of seven, but this only corresponds to a factor of safety of about 0.6. That is to say, the aeroplane by certain maneuvers could be broken in the air. This fact is well known to all pilots, and such a breakage now seldom occurs. It will be seen from the above table that in ordinary bumpy weather the loads were only increased about 1½ times normal.

Since all other increased loads arise from "stunts" it would appear that commercial aeroplanes will seldom have to contend with the heavy loads met with in war flying, and it may be possible on this account to cut down load factors especially on heavier types. The illustration shows the difference between the loads in a loop and loads due to gusty weather upon the same aeroplane.

Analysis of Weights.—As in all forms of science, progress is very largely dependent on the ability to measure accurately the various items and factors. No genius can make up for the neglect of this essential. Once all the factors, whether they be weights, sizes or performances, are accurately measured, it is not so difficult to decide in which direction to proceed. A large amount of attention was given to the careful analysis of the weights of all available aeroplanes, good or bad, and tables were prepared of which samples are given in Figs. 4, 5 and 6.



ENGINE: 250 ROLLS-ROYCE. MK. III.

TYPE: WATER COOLED V 60°
NORMAL B.H.P. 230 R.P.M. 1600
MAX. 285 R.P.M. 1850
NO FITTED ONE
PROPELLER R.P.M. ÷ ENGINE R.P.M. ·64
FUEL PER NORMAL B.H.P. HOUR = ·5706 lbs.
OIL " " " " = ·0256 lbs.
FUEL PER MAX. B.H.P. HOUR "
OIL " " " "

AEROPLANE: DE HAVILLAND 4.

TYPE: TWO SEATER-TRACTOR
No OF WINGS: BIPLANE
TOP WING SPAN 42'6" CHORD
BOTTOM " 32'6" "
MIDDLE " - "
OVERALL LENGTH 30'8" HEIGHT 10'8"
GAP: TOP TO BOTTOM TOP TO FUS.
GAP ÷ CHORD DIHEDRAL
SIZE SET: LEADING EDGE of LOWER WING to T.E.

	AREAS			WEIGHTS Lbs.	WT/SQ FT.	% WEIGHT
STRUCTURE	225	WINGS.	TOP PLANE	199	·9	
	212		BOTTOM PLANE	196	·9	
			MIDDLE PLANE	-		
			AILERON PULLEYS	5		
			STRUTS (BP =)	52		
			EXTERNAL BRACING WIRES	34		
	436		TOTAL WINGS.	486	1·1	14·1
	38	TAIL.	TAIL PLANES	17	·5	
	80		ELEVATORS	17	·7	
	4·25		FINS	9	1·0	
	13		RUDDERS	11	·9	
	79		TOTAL TAIL.	49	·6	1·4
		BODY	FUSELAGE	425		
			CHASSIS	100		
			TAIL SKID	8		
			CONTROLS (Enclosed in Fuselage)	-		
			TOTAL BODY.	533	1·2	15·1
	TOTAL WEIGHT OF STRUCTURE UNIT.			1068	2·4	31·6
POWER		PLANT.	ENGINE DRY	889	WT/H.P. 3·8	
	GALLS 0		PROPELLER	72	2·6	
			RADIATOR & PIPING & WATER	150	·6	
			ENGINE ACCESSORIES	10		
			POWER UNIT.	1120	6·2	33·2
	GALLS 59	SUPPLIES	FUEL TANKS & PIPING	55		
	· 425		OIL TANKS & PIPING	44		
	BOMBS		FUEL	232	1·5	
	-		OIL	60	·15	
	TOTAL WEIGHT OF POWER UNIT.			1668	10·2	39·3
LOAD		HUMAN	CREW	286		
			INSTRUMENTS	-		
		MOVABLE	CAMERA	28		
			W/T.	27		
			SUNDRIES	-		
			GUNS & AMMUNITION	-		
			RIGGING & GEAR	198		
			ARMOUR	-		
	TOTAL WEIGHT OF LOAD UNIT.			600	2·2	18·1
	TOTAL WEIGHT OF MACHINE			3313		100·0

FIG. 4. ANALYSIS OF WEIGHT. DE HAVILLAND 4.

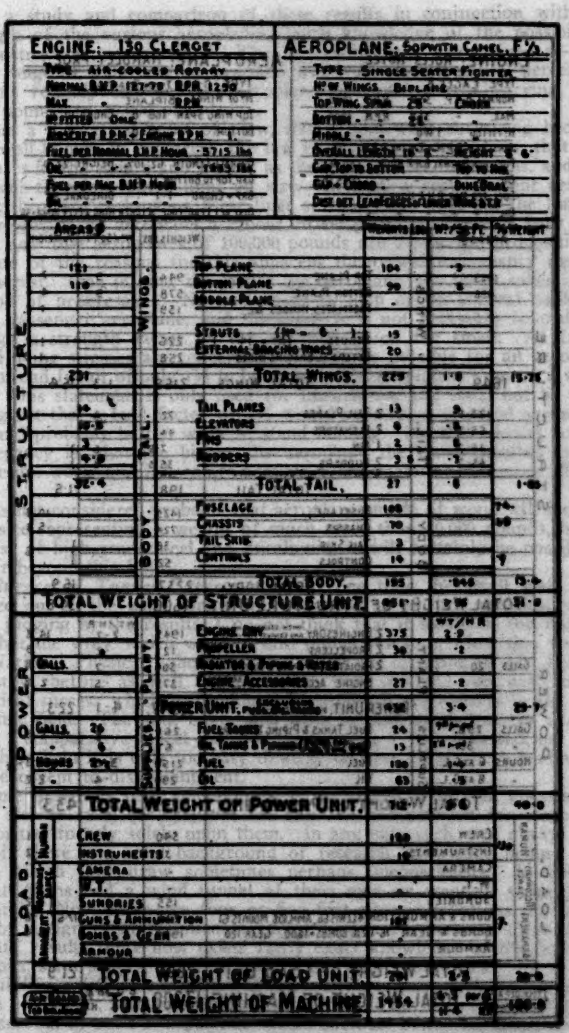
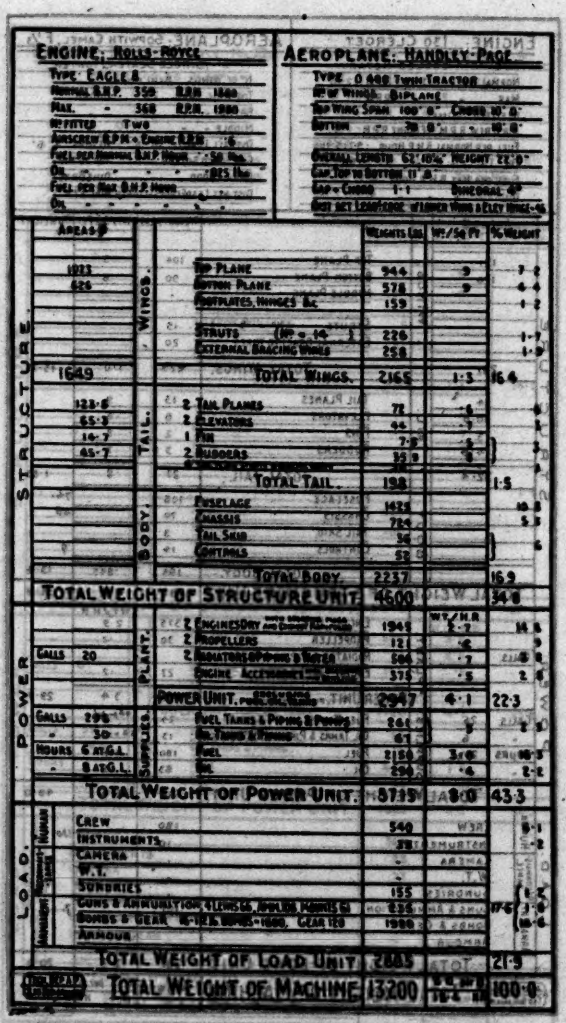


FIG. 5. ANALYSIS OF WEIGHTS. SOPWITH CAMEL.



ENGINE. ROLLS-ROYCE

TYPE EAGLE 8
NOMINAL B.H.P. 350 R.P.M. 1940
MAX. " 368 R.P.M. 1980
No. FITTED TWO
AIRSCREW R.P.M. ÷ ENGINE R.P.M. .6
FUEL PER NOMINAL B.H.P. HOUR .50 lbs.
OIL " " " .025 lbs.
FUEL PER MAX. B.H.P. HOUR
OIL " " "

AEROPLANE. HANDLEY-PAGE

TYPE O/400 TWIN TRACTOR
No. OF WINGS BIPLANE
TOP WING SPAN 100' 0" CHORD 10' 0"
BOTTOM " 75' 0" " 10' 0"
OVERALL LENGTH 63' 10½" HEIGHT 22' 0"
GAP TOP TO BOTTOM 11' 0"
GAP ÷ CHORD 1·1 DIHEDRAL 4°
NET LOAD/SQ. FT. WINGS & ELEV. 8·6

	Areas ft²			Weights (lbs)	Wt./Sq. Ft.	% Weight
STRUCTURE.	1223	WINGS.	Top Plane	944	9	7·2
	626		Bottom Plane	578	9	4·4
			Outplates, Hinges &c.	159		1·2
			Struts (No. ÷ 14)	226		1·7
			External Bracing Wires	258		1·9
	1849		TOTAL WINGS.	2165	1·3	16·4
	123·6	TAIL.	2 Tail Planes	72	·6	0·5
	65·3		2 Elevators	44	·7	0·3
	14·7		1 Fin	78	·5	0·6
	45·7		2 Rudders	14·9	·3	0·1
			TOTAL TAIL	198		1·5
		BODY.	Fuselage	1428		10·8
			Chassis	729		5·5
			Tail Skid	36		0·3
			Controls	52		0·4
			TOTAL BODY.	2237		16·9
TOTAL WEIGHT OF STRUCTURE UNIT				4600		34·8
POWER PLANT.			2 Engines dry and Chassis fittings	1949	W/HR 2·7	14·8
			2 Propellers	121	·6	0·9
	Galls 20		2 Radiators, Piping & Water	806	·7	6·1
			Engine Accessories	375	·5	2·8
			POWER UNIT.	2947	4·1	22·3
	Galls 295	SUPPLIES	Fuel Tanks & Piping & Pumps	286	·5	2·2
	" 30		Oil Tanks & Piping	61		
	Hours 6 at G.L.		Fuel	2158	3·0	16·3
	" 8 at O.L.		Oil	296	·4	2·2
TOTAL WEIGHT OF POWER UNIT.				5747	8·0	43·3
LOAD.		CREW		540		4·1
		INSTRUMENTS		238		1·8
		CAMERA		-		
		W.T.		-		
		SUNDRIES		155		1·2
		GUNS & AMMUNITION	4 LEWIS GS. 2 VICKERS MGS.	2356	MG	17·8
		BOMBS & GEAR	16 112 lb. BOMBS = 1800, GEAR 120	1920		14·6
		ARMOUR				
TOTAL WEIGHT OF LOAD UNIT				7883		21·5
TOTAL WEIGHT OF MACHINE				13200	lbs. per sq. ft.	100·0

FIG. 6. ANALYSIS OF WEIGHT. HANDLEY-PAGE O/400.

By a study and comparison of these results in conjunction with the strength of the various aeroplanes, much knowledge of the possibilities of construction was obtained. The interesting fact was arrived at—that for a range of well-designed practical war types, the structural percentage remains roughly constant for aeroplanes of total weight varying from 1,000 pounds to 30,000 pounds.

From a theoretical point of view, this is somewhat surprising because, as is well known to engineers, the law of dimensions lays down that area increases as the square and weight as the cube of the dimensions, and that this will therefore put a limit on size. In fact, a very eminent aerodynamic theorist, working on these lines several years ago, put the limit of the weight of an aeroplane at about 10,000 pounds. There is very little doubt now that aeroplanes of 100,000 pounds are a practical proposition.

Some of the reasons for this apparent theoretical discrepancy may be of interest. One is, that the larger the aeroplane, the more sober is the method of progression. No one wants to loop or do vertical banks on a big passenger aeroplane, and therefore it is not necessary to maintain as high a strength factor on the big type as on the small. As far as actual flying stresses are concerned, it would be possible for an aeroplane with a load factor of only 1½ to be flown without collapse even on a windy day. This statement is only used for illustration, and must not be taken to suggest that a load factor of 1½ would produce a practical aeroplane; it would probably be too weak to stand landing. Another reason for the discrepancy is, that the bigger the aeroplane the more detailed can be the design work, and it becomes possible to use material in a more efficient way.

It is not considered probable that aeroplanes made of wood will increase to a size representing a weight of much more than 40,000 pounds, but by the use of high-grade steel and duralumin, it will certainly be possible to go far beyond this limit.

Influence of Tunnel Experiments.—At one time the small scale work carried out in the wind tunnel was regarded as of little practical value; now, judging by the results, I do not think that it would be too much to say that the work which was put into tunnel research, when this work at the National Physical Laboratory was under the direction of Mr. Leonard Bairstow, before as well as during the war, was the real basis of the technical success which we undoubtedly attained, particularly in the aerodynamic field. The data from such work is more useful to the designer from a comparative aspect than for the absolute values obtained, but without their help it is only too easy to stray off into blind alleys leading nowhere except to disappointment.

Some designers have undoubtedly a wonderful facility in guessing the next step to take, but they are too few and far between for responsible authorities to rely solely upon them. In any case such men always work best if there is a solid background of research knowledge behind them, from which they draw sometimes perhaps unconsciously. In 1914 no private firms had a wind tunnel of their own or went in seriously for research. Now there are four or five first-class installations in constant use by designers of the manufacturing firms. As instance of more important results there now exists fairly exact knowledge of the best wing sections, strut shapes, propeller blades and body resistances.

Stability and Controllability.—There are two means of obtaining stability in an aeroplane; first, by means of an automatic device, such as gyroscope, and second, by such a disposition of the surfaces of the aeroplane that the machine has inherent stability. Very little success has been obtained from the first method, but the second is now very largely employed.

Questions relating to stability and controllability are intimately connected but in one sense they are distinct. Thus it is possible to have an unstable aeroplane which is readily controllable and very popular with pilots.

Stability may be considered under three heads:—

Longitudinal stability,
Lateral stability, and
Directional stability.

The first, longitudinal stability, is obtained by means of the tail plane, and the size of this for any particular type determines within limits the degree of stability. The fundamental point, however, is the position of the center of gravity of the aeroplane relative to the main planes. If this is too far aft no tail plane can be found to give stability. The farther forward the center of gravity, the smaller is the tail plane required.

The problems of lateral and directional stability are very closely connected, and must be considered together. Lateral stability is obtained by giving the main planes a dihedral angle, and directional stability is obtained by a proper regard to the dimensions and dispositions of the fins and rudders. The area of the fin and rudder required is a function of the dihedral angle.

The outbreak of war found us in a very favorable position with regard to the development of an inherently stable aeroplane. The importance of this feature from a military point of view had been fully realized, and special efforts had been made to produce a stable and at the same time controllable aeroplane. That these efforts were successful was largely due to the late E. T. Busk, of the Royal Aircraft Factory, as it was then called, and the B.E. 2c aeroplane, which embodied the results of his work, had been fully tested and demonstrated to possess complete adherent stability prior to the outbreak of war. Unfortunately, Mr. Busk was killed in a flying accident shortly after his experiments had been brought to a successful issue. However, his full scale research had been carried so far that the principles underlying the design of this machine could be applied to any other design of aeroplane. Subsequently nearly all machines were designed for inherent stability, except such types as were considered to be more suitable for their specific work if a certain degree of stability were sacrificed for very quick maneuverability. An impression was prevalent, at any rate during the first two or three years of the war, that a stable aeroplane must necessarily be very heavy on its controls, and since quick maneuverability was an essential for fighting scouts, the aim of designers, encouraged by fighting pilots, was to obtain the maximum controllability and quickness of handling, irrespective of stability.

It was gradually realized that this was a mistaken view, and that the comparatively poor maneuverability of some of the earlier stable machines was due, not to the fact of these machines being stable, but to the particular design of the controlling surfaces. A very great amount of research into the conditions governing stability and controllability was carried out both from the theoretical and experimental standpoint, and thus revealed enough data to enable aeroplanes to be designed combining inherent stability with good maneuverability, and as a result, the prejudice against stability, in small fighting aeroplanes quickly disappeared.

A good example of the advantage of this is afforded by Captain Ball's wonderful return to our lines on his stable S.E. 5 machine after his controls had been almost completely shot away. The aeroplane practically flew itself back, and with only half of his normal elevator control he was able to make a safe landing on the aerodrome. Such a feat would have been out of the question on an unstable machine.

At the end of the war we were calling for aeroplanes with neutral stability for fighting work, *i.e.*, aeroplanes which followed the pilot's mind and hand in whatever attitude they were put. For bombing and long-distance work stability is a very important asset, as it relieves the pilot of fatigue, and facilitates the maintenance of his course and his sighting for bomb dropping. The disadvantages of not putting a sufficient amount of study into these features are demonstrated by German practice. Although a few of their small aeroplanes were fairly maneuverable, their larger ones did not compare favorably with our own when tested under the same conditions, and in the case of their very large bombing aeroplanes we had evidence that the pilot's difficulties on a long flight were very considerable, and it is probably not too much to say that the heavy proportion of German bombers which were crashed on returning from their raids was largely due to lack of stability and controllability.

Monoplane, Biplane or Triplane.—During the war all these types have been experimented with, and, in fact, have been built on a production scale, and it cannot be definitely stated that one type is more suitable than another without knowing the exact purpose for which the aeroplane is required.

Broadly, the comparative advantages of the three types are as follows: In comparison with the biplane, the monoplane is 5 per cent more efficient as a weight carrier per square foot, and can be made to afford a better fighting view. On the other hand, it is weaker for the same weight of structure, and is less maneuverable for equal total weight. Similarly the triplane, comparing it to the biplane, is 5 per cent less efficient, but is more maneuverable, and affords opportunities for a deeper and therefore stronger main girder, which gives it an advantage for the larger sizes. Incidentally, it is also more difficult and expensive to produce. The balance between advantage and disadvantage therefore depends upon the particular function required from an aeroplane, and also on the skill of the designer in overcoming the peculiar difficulties of his problem. But the general conclusion is that the monoplane is most suited for the very small aeroplane; the biplane for all general sizes, and probably the triplane for the very large sizes. Experience during the war in general bears this out, although there have been instances which might be taken as contradictory to this statement.

The importance of the successful use the Germans made of their Fokker monoplane should not be exaggerated, as the real reason for this success was the production in large numbers of a good single-seater with a rotary engine copied from the French Gnome, combined with the new synchronized guns, and a fresh method of attack. When we tested the aeroplane ourselves, and compared it with our own under similar conditions, its performance was in fact very little superior to the B.E. 2c, against which it was so effective.

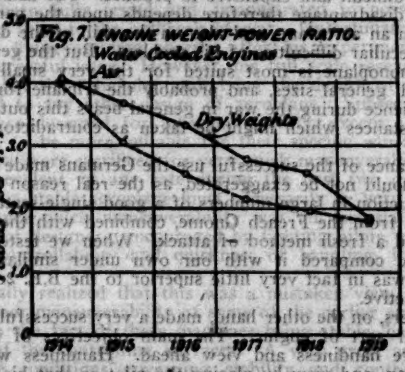
Our designers, on the other hand, made a very successful triplane fighter with a similar sort of engine. The main objectives of the designer in this case were handiness and view ahead. Handiness was obtained by very small span, and view by placing the pilot so that his eye was in the line of the center plane. However, as far as this country was concerned, the general decision was the selection of the biplane as the simplest and soundest type for all ordinary work.

Climb Requirements.—The most valuable quality in a war aeroplane and the one most difficult to supply is no doubt climb. Practically all other considerations are opposed to fast climb, such as high superficial loading, direct drive engines, high speed and long range. But the demand by pilots for a high rate of climb, both as a protection against anti-aircraft fire and to increase their fighting capacity was so great, that this quality had to be provided. The range of guns, or rather their power of accurate

shooting at a height, increased in an astonishing degree during the war. In the early days, a height of 3,000 feet was reasonably safe, and aeroplanes could do their work at that height. Then it was increased to 6,000 feet, 10,000 feet and 15,000 feet. By the end of the war shooting even at 20,000 feet was unpleasantly accurate. Whenever a new type of aeroplane appeared which could operate at an increased height, it was immune for a period, and could do its work almost unmolested, and in some cases without being perceived; but this period seldom lasted long, and sometimes even before the new type was appearing in sufficiently large numbers to count seriously, it was outranged.

The same state of affairs applied to the height at which fighting took place, which gradually increased from year to year up to 20,000 feet. In order that the pilot could fight in a satisfactory manner he required a good rate of climb as well as the uppermost position. The difficulty of providing climb in an aeroplane during the first two years of the war was enhanced by the constant increase in the number of accessories required to enable the extra military functions to be carried out. These accessories added largely to the weight and also to the air resistance, and it was not until specially designed aeroplanes appeared that the position became satisfactory.

Interaction of Engine and Aeroplane Design.—Progress in aeroplane was very much bound up with the progress in engine design; in fact, it can be broadly stated that during the whole of the war the aeroplane designers were waiting upon the engine designers, and as soon as any new engine was developed to a satisfactory point, it was but a short time before aeroplanes were in service, making the maximum use of such an engine, or at any rate a thoroughly effective use.



It is interesting to compare German practice with our own. The Germans realized at an early stage the necessity of large engines, and they concentrated their attention on the production of a first-class but simple type of motor. This had a straight row of six cylinders of an average weight per horsepower, neither excessively heavy nor particularly light. They standardized this type at a comparatively early date and consequently made early advances in production and reliability.

Our policy was by no means so definite, and our engine designers worked on a number of different types; air-cooled rotary, radial, and in V, water-cooled, eight-cylinder, twelve-cylinders in V and six cylinders in line. At no time did we rigidly standardize a single type. In consequence, we had

far bigger difficulties in production, and on the whole our motors were not so reliable. Ultimately, however, we progressed much further than the Germans, both in the power of the engine, and in the reduction of weight per horsepower.

The reduction of weight of the aeroplane per horsepower can be obtained in either of two ways: (1) By having a very powerful engine of average weight per horsepower, so powerful that the weight of the pilot and his military gear is relatively an unimportant factor; or (2) by having an engine of very light weight per horse-power. This point is best illustrated by a short analysis in weight per horsepower, comparing two aeroplanes which are both single-seated fighters, and of the same pounds per horse-power.

Large Aeroplane.	Lb./H.P.
300-horsepower engine weight	3¼
2 hours' fuel, oil and tanks	1¼
Pilot and gear	1
Aeroplane structure weight	3
	9

Total weight, 2,700 pounds.

Small Aeroplane.	Lb./H.P.
200-horsepower engine weight	2¼
Fuel, oil and tanks	1¼
Pilot and gear	2
Aeroplane structure weight	3
	9

Total weight, 1,800 pounds.

The first type has a large water-cooled engine, is economical in fuel, and by reason of the size of the engine, the pilot and his gear account for only a small proportion of the total weight; whereas on the small aeroplane the engine is a light weight air-cooled engine of heavier consumption, and the weight of pilot, etc., is a much larger proportion of the whole weight.

The two aeroplanes would practically give the same performance, but the smaller probably would be the better fighter because of its greater maneuverability. There are many other factors to take into account, such as reliability, pilot's view, ease of manufacture, etc., all of which must be considered before coming to a decision as to which is the better type.

Generally speaking the tendency during the war was towards the heavier aeroplane, although there were two periods when the light-weight engine reversed this. One was when the 80 Le Rhone Sopwith Pup supplanted the 140 R.A.F. B.E. 12, and the two 100-horsepower pushers D.H. 2 and F.E. 8; the other was when the small air-cooled Wash engine was competing with the 275 water-cooled Rolls-Royce Falcon.

Wing Structure.—General development in wing construction of aeroplanes, during the war, has been more in the nature of refinement of detail, than of evolution of methods.

With increased knowledge concerning the loads to which the structure is subjected during flight, has come the possibility of more scientific proportioning of the structural members; but beyond this the general arrangement of the wing has remained unchanged. The structure percentage weight has shown the effect of increased knowledge, and this percentage has now reached a very low value.

The effect of attention to detail has also been to give a general cleaning up and simplicity to the appearance.

In external bracing, changes have taken place in some particulars. In 1914 the duplication of the main lift wires was considered to be very important, if not essential; now, in the event of one wire getting shot away, the loads are taken through the incidence wire which are those seen when looking at a wing from the side. At the commencement of the war, hard drawn piano wire was used for the main lift and anti-flying wires in many types; when this was not used, stranded cable was employed. The use of these materials has been superseded by stream-line wires. These consist of high-tensile steel rods of a lenticular section rolled from bar. The ends are left circular, and threaded to form a simple means of attachment to the fittings. These wires have proved very satisfactory, and initial troubles, due to crystallization of the metal through vibration, having been overcome, this is now the commonest form of bracing. Hard drawn piano wire has disappeared, but cable is still extensively used, particularly in types where high performance is not essential.

The design of interplane struts has undergone certain changes. The cylinder aeroplanes had struts of stream-line section made from solid spruce, and occasionally steel tubes faired off to a stream-line form by light fairings were used. With the growth in size of aeroplanes and the increasing scarcity of suitable wood, built up or laminated struts were used. Also, with the standardization of steel tubes for aeroplane work, and an enormously increased production of these, this form of strut became very popular. It is a most efficient construction, particularly for the landing chassis.

Internal bracing wires have gone through much the same process as the main plane bracing wires—at the commencement of the war, piano wires were invariably used, but these have now almost universally been superseded by swaged rods, screwed at the ends for fitting purposes.

During the war also, the scarcity of silver spruce occasioned the development of new methods of spar construction. These were originally always in one length from the center section to the wing tip and spindled from a solid section. The first effect of timber shortage was to introduce a system of splicing, and much experimental work was carried out to determine the best form of splice to be used. The result of this work was that a straight scarf joint sloped 1 in 9 was adopted as a standard. This scarf was glued, pegged and wrapped with fabric. Its efficiency was high when compared with the solid spar, and it was a simple job when considered from a production point of view.

The splicing of spars was not found sufficient to overcome the timber shortage, and the need became evident for some change in design by which small scantling timber could be used, even for the spars of large aeroplanes. Further experimental work was put in hand, this time to determine the effect of laminating spars, *i.e.*, glueing thin strips together, and from this built-up section constructing spars in the ordinary way. At the same time experiments were made on box spars, *i.e.*, the spars, instead of being made of the common "I" section were made in box form, the flanges and webs being formed of separate pieces of materials, glued and bradded together. Both the laminated and box spars were found to be very successful, and both types were immediately put into service. No trouble has been met with from their use. Indeed, it is probable that better quality spars are obtained from this means than by cutting from the solid at any rate for large aeroplanes. The smaller the scantlings, the easier inspection becomes, and the more guarantee is there that first-class material only is being used.

Splicing and the building-up of spars have proved such successful innovations, that there is no doubt that these methods of spar construction, introduced purely as war measures to overcome the serious timber shortage, will remain as standard in the future.

Fuselage Construction.—Fuselage construction has undergone very few changes, during the period of the war, as regards methods. Larger aero-

planes have been built, and this has naturally meant greater attention to the construction, but the broad lines of design have remained fairly well the same.

There are three principal types of construction adopted in present-day practice.

1. The braced N girder fuselage (Figs. 8 and 8A).
2. The three-ply covered fuselage (Fig. 9).
3. The monocoque fuselage (Fig. 10).

The first of these consists of four longerons, or fore and aft rails, braced by a system of struts and diagonal wires in all four faces. Fabric covering completes the structure. This is the commonest type of design.

The second system retains the longerons and the vertical and horizontal struts, but in place of bracing wires and fabric, thin three-ply is glued and bradded to the framework.

The monocoque fuselage dispenses with the longerons and consists of a single sheet of three-ply or veneer molded to shape on formers.

As a general rule, three-ply frames are provided as bulkhead bracing at intervals along the length. There are several varieties of this construction, but the essence of them all is the tubular construction of thin veneer, the formers or bulkheads merely being inserted to stabilize this skin.

Of the three methods of construction, the first and third were known and adopted before the war, and modifications have been more in the nature of improvements in manufacture than in fundamental alterations in principle. The second method was, I believe, first used by the Germans in their early Albatross scout at the beginning of the war, but has since been used with great success by British designers, notably in the case of the De Havilland designs.

Monocoque Construction.—The monocoque method of construction was adopted by the Germans at an early date and was later almost universally used by them. The probable reason for this was their ample supply of high-grade three-ply, rather than any constructional or aerodynamical advantages which they attached to this method of construction.

The chief advantage from the service point of view, of a monocoque method of building fuselages lies in its invulnerability to casual bullets. In an ordinary fuselage a bullet striking a main longeron or strut might quite possibly cause the structure to collapse, whereas a monocoque will stand up to any number of bullets. A disadvantage is that truing up becomes difficult, and special arrangements are necessary to overcome this defect.

Our supplies of three-ply were deficient almost up to the end of the war, owing to the failure of the Russian supplies, and this no doubt had a considerable influence on our designers and manufacturers. One of our firms did develop a very simple method of constructing in three-ply, which would have admitted of a large production, but the particular aeroplane was not adopted for other reasons.

It was thought at one time that the rounded fish-like form of monocoque would considerably lessen air resistance, and would enable a higher speed to be developed. The importance of this, however, has been a good deal exaggerated; the advantage gained is not worth very much.

The monocoque construction offers great opportunities of development for commercial aeroplanes, as it leaves the space inside the skin free from obstruction, a very considerable advantage when carrying mails, goods or passengers, and in this respect it has a great pull over the standard braced fuselage where diagonal bulkhead bracing wires occur at every panel. It has also a considerable advantage in the almost complete absence of metal fittings, making for ease of construction.

The largest aeroplane yet built—the Tarrant Tabor—has a fuselage 11 feet in diameter, which has been built on a modification of this principle, the skin being made of layers of thin laths glued and tacked over formers

until set. The skin is stabilized by latticed hoops of wood, and the resulting structure is a very light and strong fuselage with the whole of its interior free from obstruction.

The regrettable accident to this machine on its first trial in no way reflects on the basis design of the machine.

In a flying boat, the hull has to function both as a boat, as a landing carriage, and as a fuselage, and it is not uncommon to hear of the sea-plane, as a class, being under serious disadvantage to the aeroplane, because of the heaviness of its hull. Our experience during the war has brought us to the point of being able to state that a well-designed hull is no heavier than a fuselage and landing carriage, and that sea aircraft are therefore under no disadvntage under this heading as compared with land aircraft.

Metal Construction.—There is no doubt that the future of metal construction for aircraft is very promising. The amount of work and time entailed in designing metal structures is very much greater than that required for wooden ones, owing to the experimental work involved. There is also the difficulty of introducing modifications during the production stage, modifications which were continuous, during the war, owing to service demands to meet new and unexpected conditions. During the war, therefore, metal construction has not been generally adopted. Its future, however, was clearly seen, and a great deal of experimental work was done, principally in connection with the Avro Training aeroplane. At the end of 1917, as I have said before, there was a shortage of good quality timber, and a still greater shortage was foreseen as probable in the future, owing to the demands of the enlarged programme. A big effort was made to employ metal for the Avro which was absorbing something like one-third of our total wood supplies, and which was a thoroughly well-established type, with an assured future for training purposes.

The experimental work done in this direction was very considerable, and much interest was aroused among manufacturers. As a result, it can be definitely stated that, even for such a small type, the use of metal enables the wings to be made slightly lighter and distinctly stronger than is possible with the best quality spruce. The experimental work necessary to get at this result was so extensive and protracted that the type was not actually produced in metal in quantities, but the information obtained was of the utmost value and was well worth the effort.

Experimental work was also carried out in the application of metal construction to larger aeroplanes, and there is no doubt that the constructional gain both in weight and in reliability will be more marked in the case of large types than in small ones. The uniformity of strength obtainable in metal will give it a marked advantage over wood, and will enable aeroplanes to be made without such large allowances for variations of material.

The Germans, on the other hand, were driven to the necessity of employing metal at an earlier date than ourselves, and although they never turned out any metal structure which would have satisfied us, this form of construction was very considerably employed. Their A. E. G. twin engine bomber was almost entirely made of metal, but it was relatively heavy and allowed only a very small weight of bombs or fuel, before it became dangerously overloaded. For the spars they used high-tensile steel tubes which are not altogether satisfactory for use as a combined strut and beam.

At the end of the war there certainly did appear an all-metal German aeroplane which was called the Junker monoplane. This was of a quite novel type of construction, the wings being covered with corrugated aluminium sheeting and having multitudinous internal tubular bracing. A very thick wing section was employed. The performance was not good and it is doubtful if the type would have really been of any serious value, but as a piece of construction it showed considerable merit.

The Progress of Design and Construction of Propellers.—The screw

propeller has for many years been used as an organ of propulsion for marine craft. It was not, therefore, a totally new problem with the advent of aircraft. In its use on aircraft the propeller altered its shape, and the blades became longer and narrower as compared with marine practice.

At the outset trial and error methods were applied, and a suitable propeller was arrived at only after the trial of a large number of designs. The variations met with in aircraft work are very great. At the present day, aircraft speeds vary from 40 miles per hour in the airship to 150 miles per hour in the aeroplane. The engines vary from 40 horsepower to 600 horsepower, while the propeller revolutions vary from 500 per minute to 2,200 per minute. With such wide variations in conditions a surer and quicker method of arriving at the best results was demanded. Curiously enough, aircraft propeller designers had recourse to a method devised by M. Drezweichi in 1892 for the design of marine propellers, which consisted of a mathematical analysis treating the propeller blade as a rotating wing. The method was tested at the National Physical Laboratory, and is now in general use, with the result that it is rarely necessary to test more than two propellers to arrive at the desired result. Frequently the result is obtained with sufficient accuracy in the first trial design.

The efficiencies now obtained in aircraft propellers are high, being 75 per cent as an average, and frequently 80 per cent under optimum conditions.

As regards construction, the peculiar vibration and variation of torque prevented the use of metal, which quickly fatigued and failed. For this reason and also for quickness in manufacture, wood became and still is the principal material used.

Only the highest class material was suitable, for, at the speed at which modern aircraft engines run, the radial pull at the root of a propeller blade may be as much as 5 tons, while at the same time the propeller has to pull the aircraft along, involving bending moment due to forces of as much as ½ ton per blade. The stresses due to these combined forces were satisfactorily met with for the smaller powers, but at one time it was thought that the size of engines would be limited by the maximum power which could be transmitted through a single propeller. And such might have been the case, had it not been discovered that instead of the stresses due to these two forces adding to each other, it might be arranged so that the bending stresses due to centrifugal action would completely neutralize those due to the thrust.

The only limits now imposed on propeller design are:—

1. Tip speed.
2. Constructional limitations.

As regards the first, experiments have shown that a tip speed equal to the speed of sound should not be exceeded, and to this speed we are rapidly approaching. In the standard propeller for the American Liberty engine in the D.H. 9A, the tip speed is 880 feet per second as compared with 1,050 feet per second for sound. This difficulty, however, is met by gearing the engine so as to reduce the propeller speed. Provided the engine is suitably geared so that the tip speed does not exceed 900 feet per second, there appears to be practically no limit to the amount of power which can be transmitted through a single propeller. Even with present-day methods of construction it is safe to say that 2,000 horsepower can be transmitted through a propeller mounted on an aircraft flying at 80 miles per hour and as much as 6,000 horsepower on an aircraft flying at 150 miles per hour.

As regards the question of commercial construction, development has been along normal lines; improvements have been made in the details of manufacture such as the glueing of the numerous wood laminations, and the protection of the blade with fabric and metal edgings; and the general

result has been a better and more reliable article. Nevertheless, the use of wood is not wholly satisfactory, especially for future commercial work, involving flight through tropical countries, and we therefore look forward to the solution of the problem of the metal construction of propellers.

Division into Types.—When the war began the only aeroplane function which was considered seriously by the army authorities was that of reconnaissance, and there is no doubt that the B.E. 2a, which was developed by the Royal Aircraft Factory for this function was an excellent aeroplane, thoroughly well adapted for its work.

Reconnaissance Aeroplanes.—These early aeroplanes were not intended to carry any military load other than crew, but almost from the very start of the war the military load required began to increase, with the result that all through 1915 and well into 1916 our reconnaissance aeroplanes were overloaded with all kinds of equipment, such as guns, gun mountings, cameras, wireless apparatus, etc., which were attached to any available part internally or externally. In order to carry out their requisite functions, this additional equipment was necessary, but it naturally meant a very considerable reduction in performance. The speed was brought down 10 miles or 15 miles an hour, while the extra weight and resistance had a very serious effect on the rate of climb. This is shown by the diagrams giving the performances at the different periods of the war; it is not until the latter part of 1916 that any appreciable improvement in performance can be seen, and then both the speed and the climb go up rapidly.

It was at this period that the special military aeroplanes, designed subsequently to August, 1914, first came into use, and in these full allowance was made for all equipment to be carried. The increase in performance was due not only to the higher power engines used, but also to the fact that the aeroplanes were designed to carry the equipment as far as possible internally, thus avoiding all unnecessary resistance.

As aerial tactics developed, the roles of the pilot and observer altered, and the latter practically confined himself to being a pair of eyes in the back of the pilot's head, whereas the pilot had to do all the reconnaissance artillery, spotting, etc., as well as fly the aeroplane.

Single-Seater Fighter Development.—As well as doing one's own scouting, it was necessary to stop the other side doing his or rather to stop him from taking his reports home. This meant fighting, and fighting meant guns and better performance. The early aeroplanes were soon fitted up with a Lewis gun fixed so as to fire over or at the side of the propeller disc, and actuated by a Bowden wire. This gun was at first fixed to fire upwards at a considerable angle to the line of flight, necessitating an oblique method of attack. Then later, in order to enable the aeroplane itself to be aimed directly at the objective, the gun was mounted on stands and in a line practically parallel to the propeller shaft. It was found that, by aiming the aeroplane itself rather than an independent gun, shooting was more accurate. The attachment of all this gear and weight to machines which were not designed for them was a very serious handicap, and performances were reduced 15 per cent or 20 per cent on speed and ceiling.

Late in 1915 the Germans brought out a system of synchronizing the trigger with the engine, so that the bullets went between the blades of the propeller. This was a great improvement as it enabled the gun or guns to be fixed alongside the engine, within easy reach of the pilot, and offering very much less wind resistance. The Vickers gun was quickly adapted to work in a similar manner on our tractors, and by the late summer of 1916 our single-seater fighters were on a par with the Germans'. During this period, in addition to the tractors with exposed Lewis guns, we had been making very considerable use of small single-seated pushers of remarkably good performance considering the difficulties of the proposition.

The characteristics of the Sopwith Pup, our first good tractor single-seater, were very light surface loading, a small but good rotary 80-horse-

power French engine, and every scrap of unnecessary weight eliminated by careful design. The view, particularly overhead, was not very good, but the aeroplane was so handy fore and aft that this did not interfere very seriously with its fighting qualities. This type lasted a very considerable time before it was superseded, which, in view of the comparatively small horsepower, was remarkable. During the period in which this type was in use fighting acrobatics advanced to a marked degree, and in the next type an effort was made to increase view and maneuverability. This was the Sopwith triplane with another French engine of 110 horsepower to 130 horsepower.

The loading per square foot had increased, but the loading per horsepower had decreased considerably, and the performance was better. Some of the aerodynamic disabilities of the triplane were overcome by the pronounced forward stagger and the use of a single strut. This single strut system increased the difficulties of manufacture and repair, particularly as regards truing up. Both this aeroplane and the one before it were provided with only one synchronizing gun, and the rate of fire was consequently slow.

In aerial fighting, the time in which it is possible to hold the enemy on the sights is very short, and one gun was found insufficient, apart from the considerable chance that the one gun might jam at the crucial moment.

In the next type, which was in design at the end of 1916, and came into production in 1917, we see the influence of these considerations upon the mind of the designer, who by the way was Mr. Hawker, of transatlantic fame. We have here a very simple and, though unstable, an easily controllable biplane with two guns. Enormous numbers of this type were produced in the course of the next year or two with French and English engines which increased in power up to 150 horsepower. The type was nicknamed the "Camel" because of the curious hump in the fuselage.

The next type on our list is the S.E. 5 designed at the Royal Aircraft Establishment, Farnborough. This is really a direct descendant of the B.E. 2A with which we started. It was a very long time coming into general use, principally owing to delays with the engine, a 200-horsepower water-cooled French Hispano. Opinion was by no means unanimous as to the fighting value of this aeroplane compared with the "Camel," and each type had its school of adherents. The S.E. 5 had a better performance, particularly at a height, was stable and maneuverable, very easy to fly, and had better visibility due to the pilot being farther back. On the other hand, it was much more difficult to produce and the engine and its accessories gave a great deal of trouble both at home and in the field. By this time we had reached a point where the performance of our aeroplanes was very considerably in advance of that of the Germans, who were cramped by their non-elastic engine policy.

The next type to come into general service was the Sopwith "Snipe." The engine here was a 200-horsepower B.R. 2 of British design. It would appear that this size of air-cooled rotary engine has reached, if it has not in fact surpassed, the maximum size for efficiency. The performance was rather disappointing and must be attributed to the enormous engine diameter and air resistance. Several competitive aeroplanes from different makers were tested simultaneously with this one, and the results were practically all the same. The control surfaces are balanced. In this way the necessary maneuverability was maintained, although the weight of the aeroplane had reached rather a high figure. The actual selection of this type was largely governed by the engine position which entailed the placing of orders on a production scale before trials of the actual engine and aeroplane were carried out.

Finally we come to the Martinsyde F. 4 which, although in production, was never used at the front previous to the signing of the armistice. This had another water-cooled engine—275-horsepower Rolls-Royce of high efficiency. Both aeroplane and engine were very good, and although the

former was heavy and somewhat large, it was wonderfully maneuverable. The performance reached was very high—over 130 miles an hour at 15,000 feet with a climb to that height in 12 minutes.

The increase in speed and climb from period to period is shown on Figure on page 769.

Two-Seated Fighters.—Apart from the particularly interesting case of the single-seaters, there developed from the use of the original reconnaissance type, a demand for, and a supply of two-seated fighting aeroplanes, which could do their reconnaissance work and defend themselves, if attacked. As the best method of defence has always been, and will be, to attack, these machines which were in principle defensive, became very effective in the offensive. Our two-seated pusher fighters, such as the Vickers or the F.E. 2s, gave a very good account of themselves, until the time came when their poor performance, as compared with the tractors, put them out of date.

The first really good two-seated tractor was the 1½ Strutter, so called by the Sopwith Company because of its peculiar wing strut system. This aeroplane was, and still is, one of the most efficient ever designed, and for its engine power (130-horsepower Clerget) it has never been surpassed. In it the pilot was placed as close up against the engine as possible with a very fine view ahead and downwards. The gunner was now put behind him with a rotatable Lewis gun turret. He had a very good view downwards and all round the rear. This arrangement, which is, in principle, still standard, gave a very maneuverable aeroplane owing to the concentration of the weights; and on account of its high performance the type became a very effective offensive weapon.

Early in 1917 there appeared another two-seated fighter where the qualities enumerated above were still further developed. This was Captain Barnwell's Bristol Fighter with a Rolls-Royce Falcon engine. Both aeroplane and engine were exceedingly good. The view from the pilot was improved by putting him farther back and higher so that he could see over the top plane, and being closer to his gunner, they could communicate better. Close communication in this sort of fighter is a very vital matter, and probably this type did more to establish our superiority over the enemy than any other.

Bombers.—Reverting to our original B.E. 2As, from which we have seen the development into one-seated fighters and two-seated bombers, we can trace also the development of the bomber. This was the type of aeroplane first used for bombing purposes, as soon as bombing, as a useful and military function, was appreciated. There were sporadic efforts at bomb dropping by 80 Gnome Avros, but when it developed into organized attacks with numbers of aeroplanes, the original reconnaissance type was used. As soon as the real requirements of this work were understood specially designed aeroplanes appeared. In the early types the bombs were fitted in all kinds of ingenious but crude ways, with pieces of string and cutting knives, etc., and the attacks were made by diving to a low height and planting the bombs by the pilot's judgment. Although great efforts were made in the training of bomb droppers and in the perfection of sighting and releasing apparatus, etc., accuracy from a height was never really obtained, and experiments conducted towards the end of last year, proved conclusively that the only way to hit any isolated object with certainty was to dive to a low height before letting go the bombs. Nevertheless the moral effect of bombing is immense in disturbing industrial work and the manufacture of munitions.

With the introduction of the B.E. 2c, systematic bombing of the enemy's positions was carried out, but this aeroplane was capable of making comparatively short raids only, and when loaded with bombs could not carry an observer. With its moderate speed it was rather an easy prey for enemy scouts under such circumstances.

The Martinsyde single-seater bomber with the 120 and later the 160 Beardmore engine was a distinct advance as regards range, while its greater speed made it a much better fighter.

As bombing developed, a subdivision of type into definite branches took place. These were day bombers, short distance and long distance; and night bombers, short and long distance. From an aerodynamic point of view the design of a high-speed, long range weight-carrying aeroplane is an exceedingly difficult problem, but it can be fairly stated that our designers, particularly Captain De Havilland of the Aircraft Manufacturing Company, found the solution in advance of those of other countries. His aeroplanes eventually had wing surfaces of high efficiency and of high superficial loading, combined with structures of great cleanliness and low air resistance, and with the most powerful engines available at the time. Owing to their low weight per horsepower his machines could get off easily though at a high speed, and were very fast in the air. On returning home, after the fuel was consumed and the bombs dropped, they could land easily enough, but if by chance they had to land with full load on board, the pilot's difficulties were considerable.

Just as the original B.E. 2 was the first used for bombing by day, similarly it was the first type to be largely employed for bombing by night, for which function it was very fairly suited, up to the limit of its capacity, as it was very easy to fly and to land. The weight-carrying capacity was, however, not great, as the engine was only 70 horsepower to 100 horsepower. When the bigger engines became available this bombing work was taken over by the F.E. 2 pushers, which were good weight carriers and had a better view for bomb sighting.

The above remarks apply more to the military flying corps than to the naval service, which made use of any aeroplanes they could get hold of, particularly French ones, such as Caudrons and Farmans. Later, they used the Sopwith 1½ strutters, and finally Handley-Pages. This latter type was the first really effective design of night bomber, and came into use early in 1917. Its general features are so well known that it is unnecessary for me to enlarge upon them. When, in the autumn of 1917, a big program of bombers was laid down, this was the type decided upon. The Vickers-Vimy was a later machine of the same general type embodying more recent experience.

At the end of 1917 it was considered to be worth an attempt to make a very long range bomber, to attack Berlin itself, from a base in England. The actual point-to-point distance is about 450 miles, and a minimum range of 1,100 miles was decided upon. As the aeroplane would have to fly by day, as well as during the night, it was essential to provide a very complete gun defence system. This meant a crew of seven, with many guns and much ammunition, apart from wireless telegraph apparatus and bombs. It was clear that it would be necessary to employ a very large aeroplane with powerful motors. The 350 Eagle Rolls being the biggest and best geared engine available, it was decided to employ four, using a system of tandem propellers, which theoretical investigation showed to be reasonably efficient. The main lines of the design were quickly arrived at, and arrangements made for the building of a few experimental aeroplanes, by a large firm of shipbuilders in Ireland. In order to get a straight run on the design and to avoid interruption, Mr. Handley-Page, the designer, went over to Ireland with a large proportion of his design staff, and after six months of very hard work, the first of the batch came over to Cricklewood, to be erected and tested. Many difficulties, particularly connected with the control, were encountered and surmounted, and on November 8, three days before the armistice was signed, two of these aeroplanes were standing ready and fully equipped to start for Berlin.

GROUND FIGHTERS.

Armoured Aeroplanes.—In the very early days of the war the aeroplane had little to fear from enemy action provided it crossed the lines at any height above about 3,000 feet, so as to be out of range of ordinary rifle fire from the ground. The introduction of the special anti-aircraft gun, however, very quickly altered this state of affairs, and the aeroplane was driven higher as the accuracy of fire improved; until, at the end of the war, there was no immunity from danger from anti-aircraft fire at a height of 20,000 feet.

For a long time it was considered that the risk of a low-flying aeroplane being hit by rifle or machine-gun fire from the ground was so great that we should not be justified in using our pilots and aeroplanes in this way. The remarkable escapes experienced from time to time by pilots forced to return across the lines at very low altitudes, however, encouraged the idea that the risks of low flying had been a good deal exaggerated, and a most effective mode of attacking the enemy was gradually developed. The first important success in this direction was, I believe, achieved by Lieutenant-Colonel Bishop, V. C., who attacked an enemy aerodrome soon after daybreak. After riddling the officers' and men's quarters with bullets from his machine guns he turned his attention to the German aeroplanes which had been brought out to attack him. He put two or three out of action on the ground, brought down three in succession as they got into the air, and then returned safely to his own aerodrome. Thereafter this method of attack developed very rapidly, and it proved of the greatest value later on, not only in breaking up the dense infantry formations advancing to attack us after March 21, 1918, but in demoralizing the retreating enemy when we subsequently advanced. A system of co-operation between our low-flying aeroplanes and the infantry was also evolved, and this proved of the greatest value in keeping the infantry and the headquarters behind in touch with what was going on in front. The aeroplanes used were the single-seater fighter—especially the light, maneuverable "Camel"—for attacking ground targets from very low altitudes; and the standard artillery machine for the infantry co-operation from rather greater altitudes.

Our casualties in these operations were naturally heavy, and the problem of providing a suitable armored aeroplane arose. As a result the Sopwith "Salamander" was designed, and was just about to make its appearance in the field at the time of the armistice. This was a single-seater fighter with B.R. 2 engine, equipped with two Vickers' guns and a very large amount of ammunition for attacking ground targets, while it carried nearly 650 pounds of armor plates, so arranged as to give the pilot and all vital parts of the aeroplane adequate protection from German armor-piercing bullets fired from the shortest ranges. In spite of this heavy load it had a speed of 125 miles per hour, and was sufficiently maneuverable for the pilot to make the attack by diving at the target, thus getting the advantage of firing in the direction of flight. Had the war lasted a few months longer this aeroplane would probably have done most effective work in hastening the German retreat.

An armored two-seater for infantry co-operation was also designed and produced, but like the "Salamander" it was too late to come into actual service.

PART III.—PROGRESS IN ENGINE DESIGN.

Before 1914 it may be said that aero engine design had merely reached the stage of sufficient reduction of weight/power ratio to enable aeroplanes to fly. Beyond this, practically no special adaptation to aeroplane requirements had been attempted. The development of the aerial arm in the war, however, speedily emphasized the importance of other factors. The

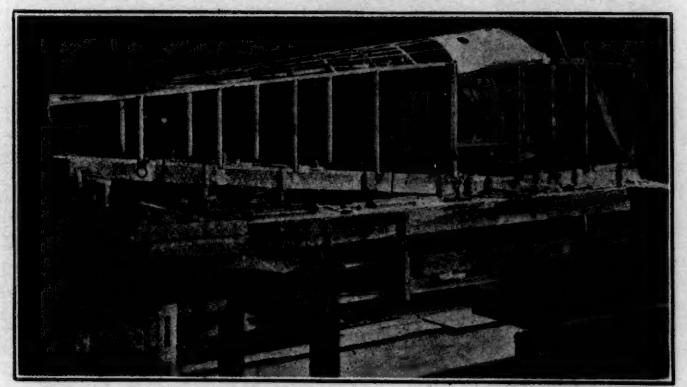
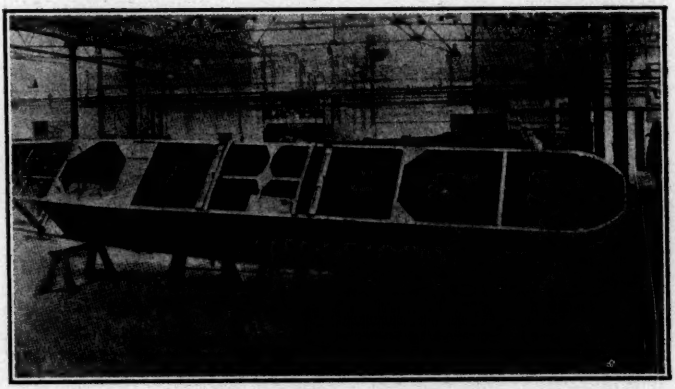


FIG. 8.—BRACED N. GIRDER FUSELAGE. FAIREY.
FIG. 8A.—BRACED N. GIRDER FUSELAGE. CAMEL.



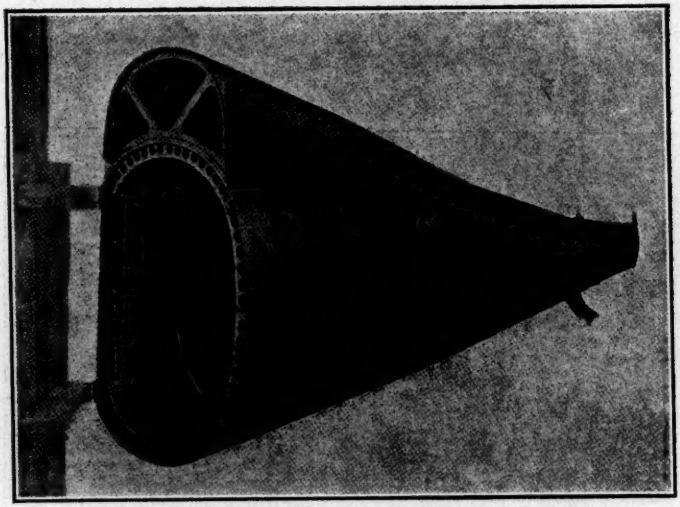


FIG. 9.—THREE-PLY COVERED FUSELAGE. DE HAVILLAND 10.
FIG. 10.—TYPICAL MONOCOQUE FUSELAGE (PARNALL PANTHER).

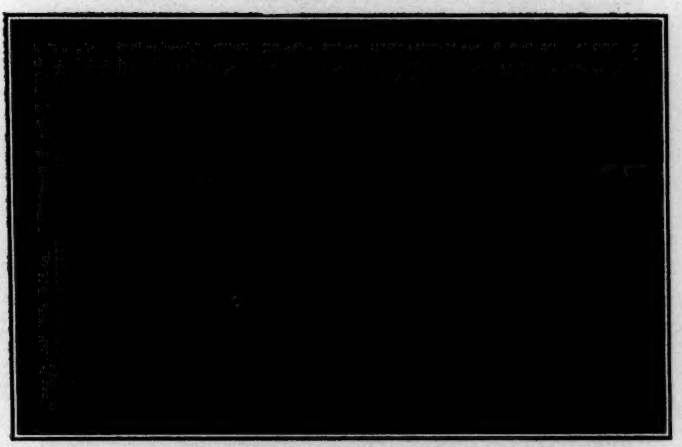


FIG. 11.—METAL CONSTRUCTION. VICKERS DURALUMIN.
FIG. 12.—TANDEM PROPELLERS. HANDLEY PAGE V. 1500.

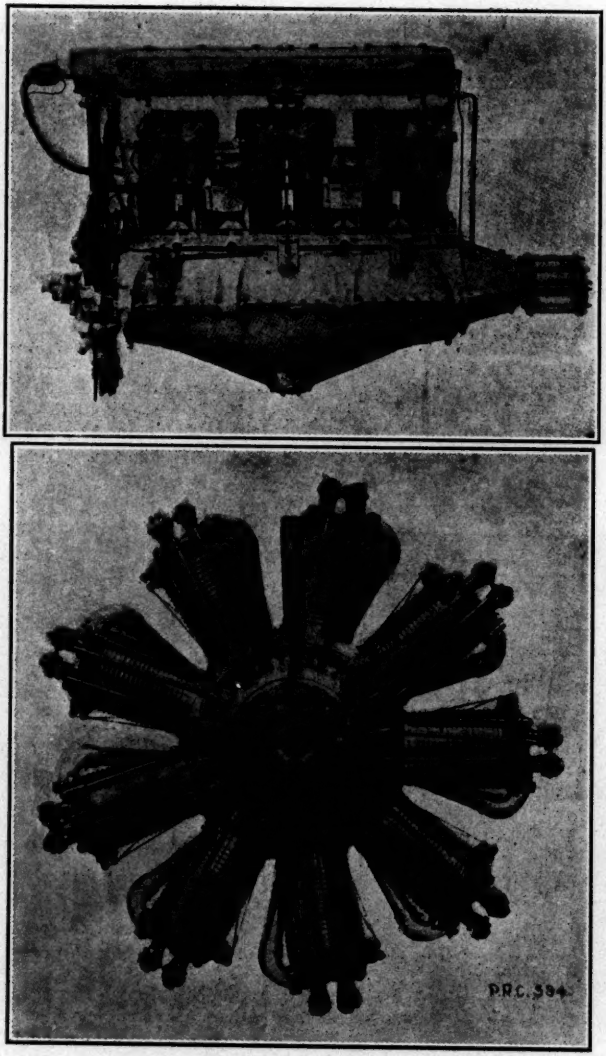


FIG. 14.—230 "PUMA" (SIDDELEY).
FIG. 15.—BENTLEY ROTARY.

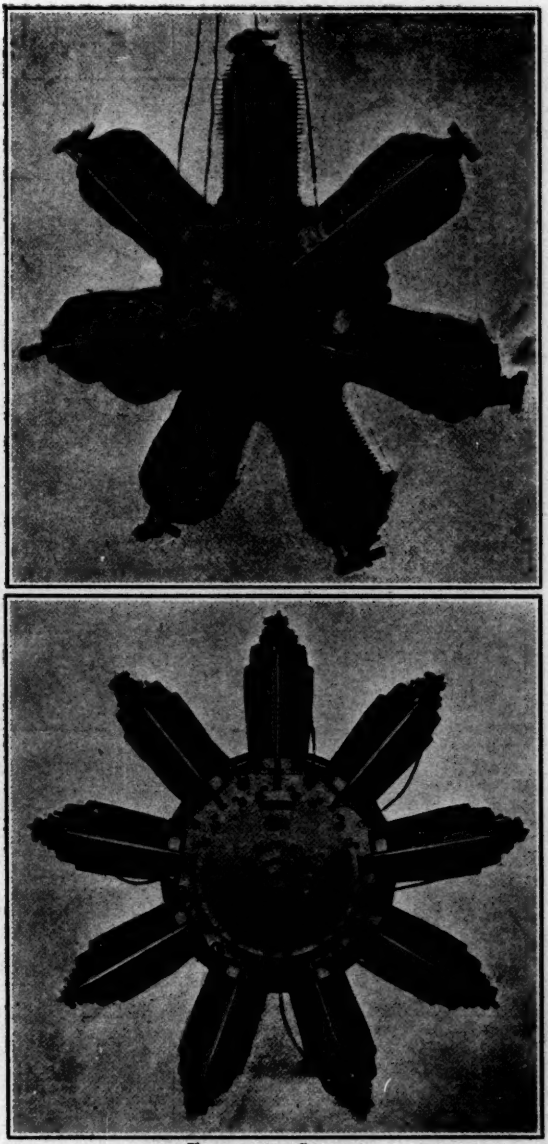
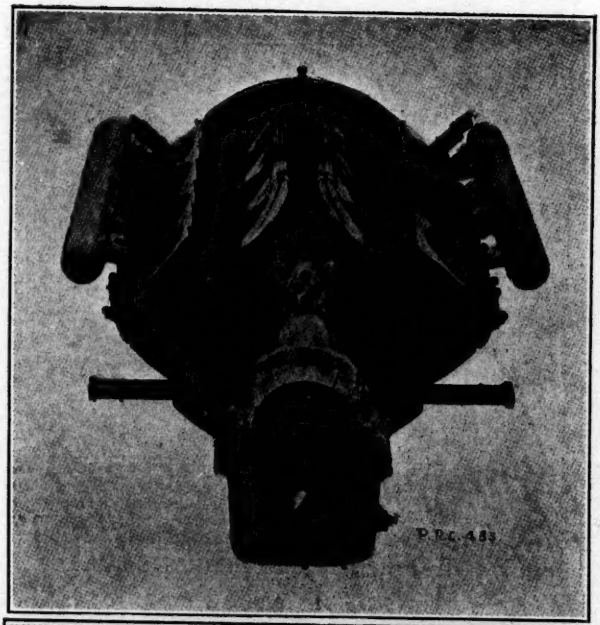


FIG. 16.—80 GNOME.
FIG. 17.—A.B.C. DRAGONFLY.



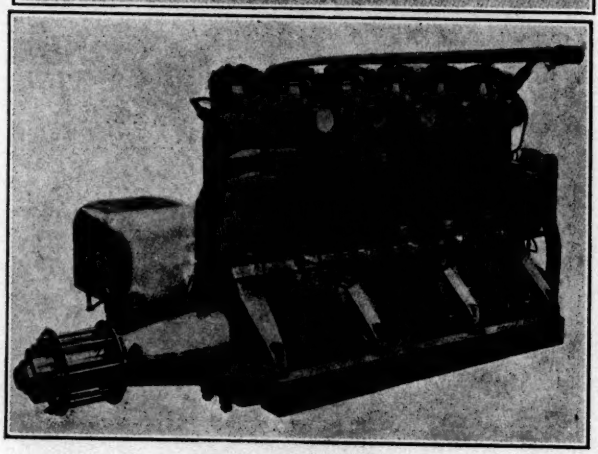


FIG. 18.—RENAULT.
FIG. 19.—160 BEARDMORE.

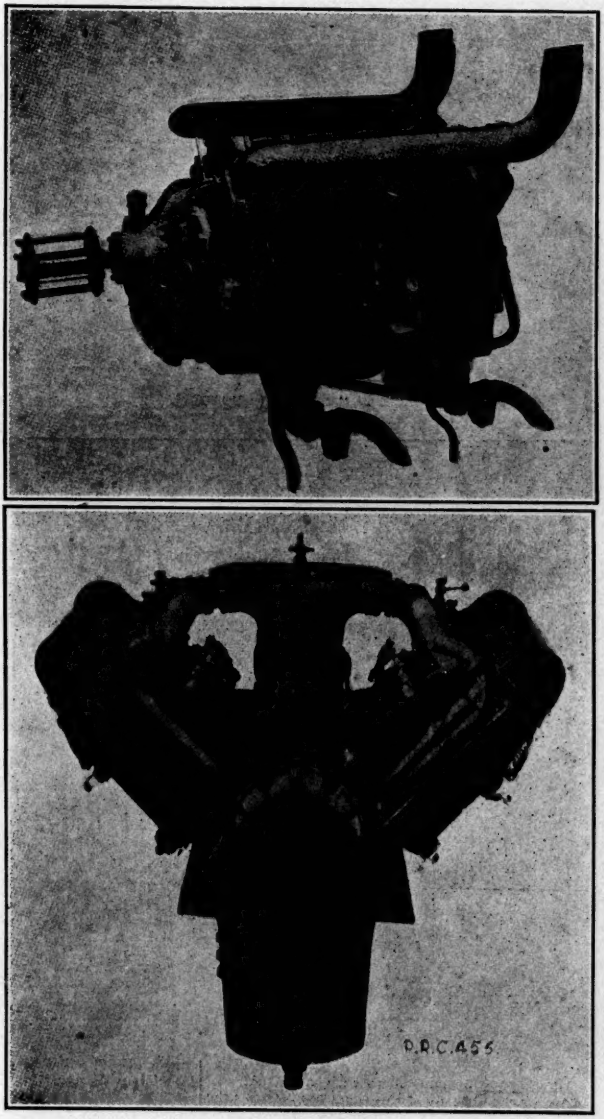


FIG. 20.—140 R.A.F. 4A.
FIG. 21.—HISPANO-SUIZA.

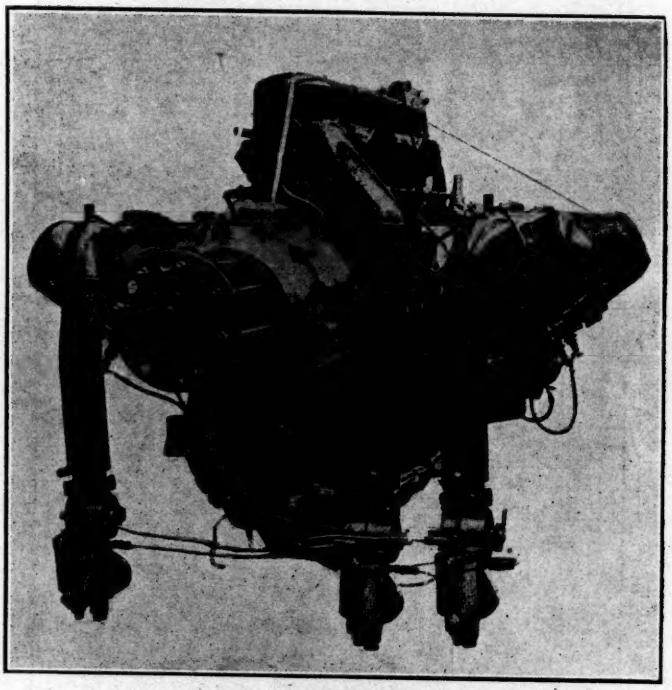


FIG. 22.—NAPIER LION.

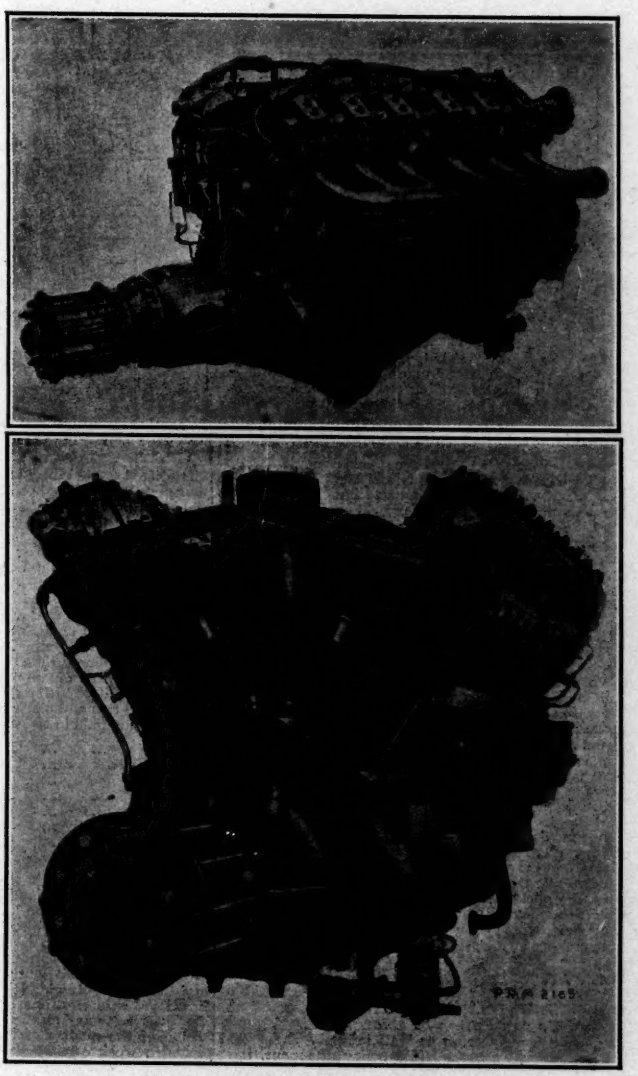


FIG. 23.—350 ROLLS-ROYCE EAGLE VIII.
FIG. 24.—550 GALLOWAY ATLANTIC.

extension of the range of operations and the losses of machines, due to engine failure, raised insistent demands for greater reliability, whilst the necessity for easier maintenance called for engines of greater all-round accessibility.

The rapid progress of flying skill and the adoption of aerial acrobatics in fighting created a demand for engines of short length and quick controllability.

The desirability of carrying out reconnaissance untroubled by enemy attack or anti-aircraft fire focussed attention on the necessity of increasing the ceiling or maximum height of operation. Coping with this most important requirement again produced an improvement of the weight/power ratio, and the ceiling of approximately 7,000 feet in 1914 was increased to nearly 30,000 feet by the beginning of 1919. It must be remembered also that the diminished density at great height decreases the amount of oxygen taken into the engine, and therefore the power which the engine can deliver. At 15,000 feet, for instance, a 300-horsepower engine can only deliver about 200 horsepower.

The extension of bombing activities at long ranges emphasized the importance of the study of the fuel consumption which, for a flight of 6 hours, amounts to a large weight per horsepower. The question of the thermal efficiency had therefore to be studied in conjunction with the weight-power ratio, so that engine speeds increased whilst the aerodynamic requirements of the machine demanded reduced propeller speeds.

Long before the end of the war the power requirements of some aeroplanes and seaplanes had far outstripped the possibilities of any one engine, so that machines possessing two, three, four, or even more engines, were in service or being built.

An important factor affecting aero engine development is the time which is required to produce a new design. Generally about eighteen months would have to elapse between the commencement of the design and a useful flow of reliable production engines. During most of this period no useful practical experience can be obtained as to the qualities or defects of the new design, and by the time bulk experience of its behavior in service is available, it is necessary to supersede it by another more advanced type. Less than half the time is required for the development and trial of an aeroplane design, so that the aeroplane is generally well ahead of the engine for which it is designed.

In 1914 our aircraft engine position was by no means satisfactory, and we depended for a large proportion of our supplies on other countries, principally on France, whose Gnome and Renault engines were pre-eminent. Great efforts were immediately made to extend our sources of design and supply, and by the end of the war British engines had gained foremost place in design, and were well up to requirements as regards supply.

Many of the earlier designs were considerably influenced by previous automobile engine practice, but a wide divergence of design and detail soon took place due to the entirely different nature of the conditions to be faced. In automobile practice silence and good carburation over a wide variation of speeds and loads were the most important features, whereas those points are of small importance for an aircraft engine. The task of the aero-engine designer was still further complicated by the fact that the order of importance of the various features of the engine is different according to the class of machine for which the engine is being designed. Certain entirely novel conditions had to be met and their attendant difficulties overcome. For example, an aero engine must have the ability to function in practically any position and, for a time at least, when completely inverted. This requirement has had a far-reaching effect on the lubrication system of aero engines, as it practically precludes the carrying of oil in the crank-case.

The shape of the engine is a matter requiring careful consideration for aircraft, as head-resistance, accessibility and small moment of inertia are

all features of considerable importance dependant on the shape. The wide ranges of temperature and pressure through which an aeroplane may pass affect the carburation, the cooling system, the lubrication system, and even the ignition, to a very serious degree. An aeroplane may undergo a very rapid change of as much as 75 degrees F. in temperature, combined with the maximum difference in moisture content of the air. With water-cooled engines, therefore, it has been found necessary to put a thermometer in the circuit and fit the radiator with blinds operated by the pilot, and even with such accessories the maintenance of the water at a constant temperature has often been a matter of great difficulty, and has thrown a heavy responsibility upon the pilot. At the same time evaporation losses must be reduced to a minimum, as the amount of water lost on long journeys is an important feature, so much so that it is true to say that the Atlantic could not be flown today with any of the water-cooling systems that were deemed sufficient at the outbreak of war.

The intense vibration due to the conditions of high speed and lack of rigid support under which aero engines must work impose new and severe conditions mechanically on every part. The violent and varying slip stream from the propeller also imposes a new problem as regards carburettor intake conditions, where again the seriousness of fire risk has to be taken into account and avoided. Probably no detail of the whole engine process has received more expert and prolonged attention than the ignition, and much of the increased reliability and efficiency of the modern engine undoubtedly results from this work.

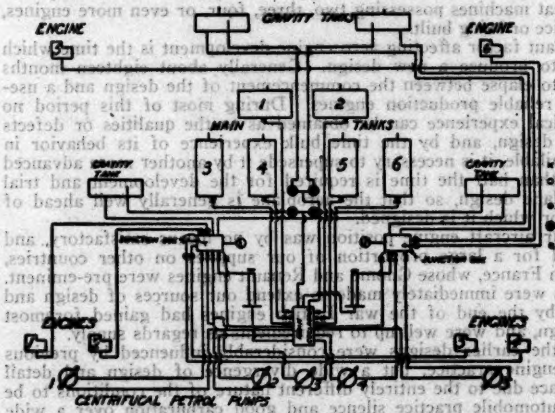


FIG. 13.—PETROL SYSTEM.

The very severe centrifugal and inertia effects which are experienced in aerial fighting, coupled with the necessity under such conditions of immediate response to the throttle, have necessitated careful design of the petrol supply system to ensure a constant and adequate supply of fuel.

In addition, the length and ramifications of the fuel system have increased considerably with the growth in the size of machines and in the number of engines. Fig. 13 shows a typical lay-out of petrol system for a large modern multi-engined machine. The main tanks are numbered 1, 2, 3, 4, 5 and 6, and have a combined capacity of 1,800 gallons of petrol.

These six tanks feed by gravity to the main collector which is situated in the engineer's cabin. In each of the pipes between the collector and tanks is fitted a non-return valve to obviate any possibility of the petrol running from the top tanks into the bottom as these six tanks are not all on the same level.

From this collecting box the petrol is lifted by five centrifugal pumps, which are shown below, into the junction boxes, which feed the engines. These centrifugal petrol pumps are driven by airscrews which are placed in the slip stream of the propellers in order that the petrol shall be pumped up whilst the machine is stationary. If these pumps should fail to act the petrol can still be lifted to the junction boxes by the hand pumps shown one on each side just above the collector.

The two distributors or junction boxes feed the engines; that on the left feeding the four bottom engines, whilst the other supplies the two top engines. As the petrol supplied to these distributors is more than that used by the engines, the extra amount passes up to four small gravity tanks which will be seen in the illustration and which are situated in the planes. These hold about 15 gallons each. As the excess of petrol continues the gravity tanks overflow through return pipes into the main collector. In these pipes flow indicators are fitted in order that the engineer may see that the system is properly working. After the main tanks are empty and no more petrol is supplied to the distributors the petrol flows from the gravity tanks into the junction boxes which ensure a further 60 gallons. The two junction boxes are fitted with indicators to show the pressure or head of petrol supplied. They are also fitted with relief valves discharging back into the collector. The collector is also fitted with a large filter, through which all the petrol passes on its way to the engine.

A great deal of progress has been achieved in the general arrangement of the engine and its cylinders so that the most effective use is made of all the material. With cylinders in line the deadweight loss per horsepower will rapidly decrease after the first cylinder, but after about four cylinders the economy to be gained by adding more cylinders practically ceases owing to the increased size of the crankshaft and bearings required to resist torsion. This naturally leads to grouping the cylinders in two rows in V form working on a common crankshaft, with two connecting rods to each crank-pin. Many such engines have been made with two rows of either four or six-cylinders each. Further extension of this principle has enabled Messrs. Napier to produce a twelve-cylinder engine of 450 horsepower, with three rows of four cylinders (three connecting rods to each crank-pin), and weighing only 1.86 pounds per horsepower dry weight.

In addition to placing cylinders in line, designers have from the earliest days of aero engines been attracted by the scheme for mounting all the cylinders radially around a common crank. By this arrangement the length of crankshaft and crank-case is, of course, reduced to a minimum, and there have been engines with three, five, six, seven, nine, ten, and fourteen cylinders in one or two planes. Of this type the Cosmos Company have produced a 450-horsepower nine-cylinder air-cooled radial engine, which weighs only 1.47 pounds per horsepower, or less than one-third the weights of similar type French engines of 1914-15.

Radial engines include those of the rotary air-cooled type, and progress in this type can be best indicated by taking the French 80-horsepower Gnome of 3.26 pounds per brake horsepower, and comparing it with the British Bentley engine of 230 horsepower, weighing only 2.165 pounds per horsepower, a reduction of about 30 per cent in spite of the tremendous increase in the centrifugal load. With radial engines of large size, however, the increased head resistance is a serious objection, and it is not likely that this method of arrangement can be extended indefinitely as regards size.

PARTICULARS OF REPRESENTATIVE BRITISH AERO ENGINES OF EACH TYPE, MAY, 1919.

Type.	Method of Cooling	No. of Cylinder.	Bore m/m	Stroke m/m	Compression Ratio—to 1.	Piston Speed ft. per minute.	B.H.P.		Speed		M. E. P.		Normal Propeller Speed	Dry Weight in Lbs.	Lbs. per H. P.		Petrol Lbs. per Normal H.P. Hour	Oil Lbs. per Normal H.P. Hour
							Normal	Max.	Normal R. P. M.	Max. R. P. M	Normal	Max.			Dry	Wet		
Bentley, Rotary 2 (Fig. 15)	Air	9	140.00	180.00	5 26	1,536.0	230	234	1,300	1,360	92.0	.....	1,300	498	2.165	...	0.63	0.088
A. B. C. Fixed Radial, "Dragon-fly" (Fig. 17)..	Air	9	139.7	165.09	4.42	1,787.5	320	350	1,650	1,750	110.0	.....	1,650	635	1.98	...	0.585	0.028
Straight Six, Siddeley, "Puma" (Fig. 14).....	Water	6	145.00	190.00	5.00	1,558.0	250	266	1,400	1,500	115.0	123.0	1,400	645	2.58	...	0.6	0.062
2 rows of 4 V. at 90 deg. Sunbeam, "Arab".....	Water	8	120.00	130.00	5.3	1,707.0	212	220	2,000	2,100	112.0	.....	1,200	550	2.6	3.24	0.486	0.039
2 rows of 6 V. at 60 deg. Rolls-Royce "Eagle" 8 (Fig. 23).....	Water	12	114.29	165.09	5.3	1,950.0	359	368	1,800	1,900	127.2	131.4 at 1,500	1,080	926	2.58	3.23	0.5	0.025
2 rows of 6 V. at 60 deg. Galloway, "Atlantic" (Fig. 24)	Water	12	145.00	190.00	5.4	1,872.0	550	575	1,500	1,600	126.3	.....	1,500	1,150	2.09	2.74	0.504	0.045
2 rows of 6 V. at 60 deg. Rolls-Royce "Condor"	Water	12	139.69	190.5	5.1	2,187.5	610	656	1,750	2,000	129.0	129.4	971	1,350	2.21	2.86	0.495	0.0225
3 rows of 4 V. at 60 deg. Napier "Lion" (Fig. 22)	Water	12	139.69	130.17	5 55	1,708.0	450	468	2,000	2,100	122.0	126.0	840	1,318	1 86	2.51	0.495	0.0225

A saving in weight and great improvement in mechanical efficiency have been obtained by eliminating the valve tappet rods and substituting overhead camshafts operating directly on the valves. Further economies have been effected by the employment of aluminium for the cylinders fitted with either steel or cast-iron liners. Pistons are now universally made of aluminium, and the gain in mechanical efficiency has been of even greater importance than the saving of weight. Hundreds of other details have also been the subject of most exhaustive study and improvement.

The question naturally arises, how is it that such results have been obtained in such a short time and in face of so many difficulties with regard to labor and material. In the first place, the result has been obtained by the free use of money; the question of expense could naturally not be allowed to stand in the way of progress in this all-important matter. Money has been spent on research, on steels and other materials, processes of manufacture, inspection organizations, etc., and the amount of scrapping of material and parts not up to standard has been on a scale that no commercial firm could adopt, and live. The greatest credit is due to the steel manufacturers for the manner in which they collaborated with the Government on the evolution of special steels and the preparation of standardized specifications. The table on page 766 gives the principal particulars of some of the leading engines of today.

Part IV.—Navigation and Meteorology.

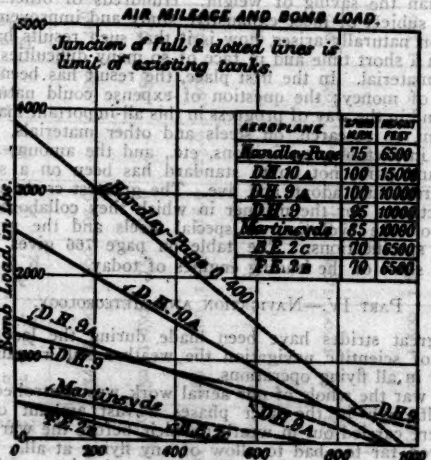
Although great strides have been made during the last year in the development of scientific navigation the weather still remains the dominating factor in all flying operations.

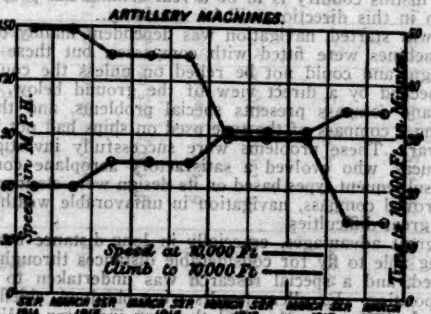
During the war the whole of our aerial work was controlled by weather conditions, although in the later phases a vast amount of successful operations were carried out in weather which, before the war, would have been considered far too bad to allow of any flying at all. The problem of flying in anything like a thick fog or ground mist remains unsolved, and if flying in this country is to be a real commercial proposition much solid research in this direction will be necessary.

When the war started, navigation was dependent mainly on map reading. Our machines were fitted with compasses, but these were of indifferent design, and could not be relied on unless the course could be frequently checked by a direct view of the ground below. The design of an aeroplane compass presents special problems, and the errors involved in using a compass of the type used on ships had not been realized before the war. These problems were successfully investigated by the late Keith Lucas, who evolved a satisfactory aeroplane compass. This compass and subsequent types based on its design were standardized. Even with the improved compass, navigation in unfavorable weather conditions still presents great difficulties.

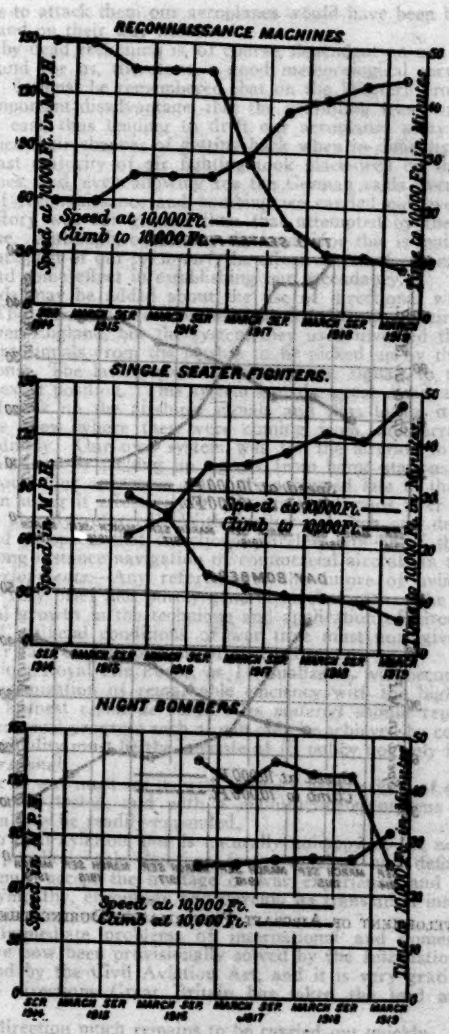
The very great advantages, especially in long-distance bombing operations, of being able to fly for considerable distances through clouds were clearly realized, and a special research was undertaken to make this a practical proposition. Excellent results were obtained, chiefly due to the introduction of an instrument called the turn indicator. When flying in a cloud or a fog bank the pilot loses all sense of direction, but this instrument used in conjunction with the compass enables him to steer a straight course, even in these circumstances.

At the time of the signing of the armistice we were training pilots in large numbers in the use of these instruments, and there is no doubt that the Germans would have had some unpleasant surprises a few months afterwards, when formations of bombing aeroplanes would have suddenly emerged from the clouds over the objectives when the inhabitants below might reasonably have considered themselves safe. Before any attempt

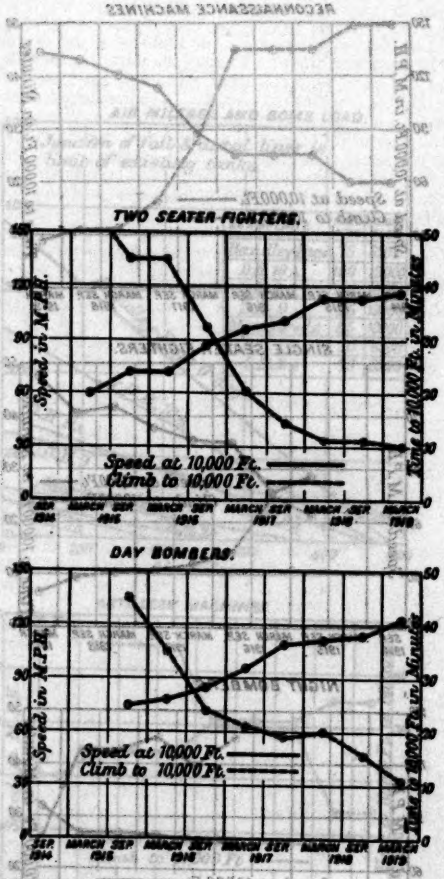

AIR MILEAGE AND BOMB LOAD.
Junction of full & dotted lines is limit of existing tanks.
AEROPLANE. | H.P. | WEIGHT
Handley-Page | 75 | 6500
D.H. 10 A | 100 | 15000
D.H. 9 A | 100 | 10000
D.H. 9 | 95 | 10000
Martinsyde | 85 | 10000
A.E. 2 C | 70 | 6500
F.E. 2 B | 70 | 6500
Bomb Load in Lbs.
Air Miles.
Handley-Page 0/400
D.H. 10A
D.H. 9A
D.H. 9
Martinsyde
F.E. 2B
A.E. 2C
D.H. 9A
D.H. 9



DEVELOPMENT OF AIRCRAFT PERFORMANCE DURING THE WAR.



DEVELOPMENT OF AIRCRAFT PERFORMANCE DURING THE WAR.



DEVELOPMENT OF AIRCRAFT PERFORMANCE DURING THE WAR.

could be made to attack them our aeroplanes would have been back in the clouds again and on their way home.

Navigation by dead reckoning is, of course, dependent on meteorological observations and for us, therefore, a good meteorological service was a *sine qua non*. It must be remembered that on the Western front we had always this important disadvantage, that the prevailing wind was blowing from west to east, thus tending to drift our aeroplanes away from our lines and reduce their chances of getting back when in difficulty. In spite of this the vast majority of air fighting took place well on the German side of the lines, and, even allowing for the German raids over England, the amount of reconnaissance and bombing we carried out over German occupied territory was far greater than that attempted by them on our side of the line. Although, of course, the credit for this is mainly due to the magnificent spirit of our *personnel*, the effectiveness of our meteorological service had some effect in establishing our ascendancy.

A few words may be added about the use of directional wireless for navigation. The Germans used this method for directing their Zeppelins in the raid over England, but the system they used involved the sending out of frequent signals from the airship to be picked up by the German wireless stations. The latter would then send out signals to the airship indicating its exact position. This system had the great disadvantage that we also could pick up the airship's signals and thus locate its position. So we always knew where they were coming from, and arranged our defence accordingly. Our own system was for the aircraft to carry the directional coils, and by picking up signals from home stations, to locate its own position. Our apparatus was only perfected late in the war, but we counted on using it effectively in the projected raids over Berlin, to which I have already referred. With further research and development there are good prospects that directional wireless will be of the greatest value in the long distance navigation of commercial aircraft in the future.

Future Developments.—Any reference to the future of aviation must necessarily be very brief and purely general in character. The rapid and quite abnormal growth in the technique and application of aircraft under the stress and artificial conditions of war time must now give place to the more sober rate of development of peace time.

Our peace-time Royal Air Force, as I visualize it, will become a relatively small organization of remarkable efficiency with the highest ideals and with the keenest *esprit de corps*. Its *materiel* should represent the last word in technical progress such as can only be achieved by considerable expenditure. Quality must be the keynote of its policy not only in *materiel* but also in *personnel*.

An outbreak of war must see us with the very best designs of engine and aircraft, tried and tested, and with a manufacturing nucleus on which war production may be readily expanded.

In regard to civil aviation, one is naturally unhappy at the necessity of adopting the prophetic role, but one factor is clear and definite. Our Government must accept the heritage of war experience, and by action, support and sympathy, encourage and develop its translation into the new channels of peace requirements.

The more immediate problems of international and domestic aerial legislation have now been provisionally solved by the International Aerial Convention and by the Civil Aviation Act, and it is very gratifying that in both these directions Great Britain has taken the lead and shown the way.

In another direction much remains to be carried out quickly. Our great mercantile marine in all its technical perfection would avail but little without our harbors, docks, lighthouses, charts, and navigational instruments. We possess fleets of aircraft of reliability and of great performance possibility, but our navigational facilities are still almost non-existent,

and herein lies one of the main fields of action of our new Department of Civil Aviation.

In all considerations for the future of Civil aviation, the two qualities of outstanding merit appertainable to the new form of transport are speed and independence of action as against land transport requiring roads or rails. These constitute the only assets for any commercial future. Speed in transport is associated with high cost, and speed will always command a high value. Early action should be taken, in regard to a few main routes, especially in countries with equable weather conditions, and especially in new countries, backward in rail development.

To such main routes would be Egypt to India, and Egypt to South Africa.

Another early development with immediate possibilities will be the use of large flying boats for inter-island and coastal traffic, for example, in the West Indies and New Zealand. The independence of the flying boat in regard to costly aerodromes, and its higher degree of safety in regard to landing places is a factor of great immediate importance. The Government and the large existing transport companies, shipowners and railways might well collaborate in their early efforts, as the initial financial results will not be healthy enough for entirely new enterprises.

Another aspect must not be neglected—the encouragement of the sporting and popular use of aircraft—and it would appear essential that the great number of war aeroplanes surplus to Air Force needs should be distributed at a low price and as early as possible to the many small enterprises and even to individuals so that the community at large may have their present enthusiasm and interest in aviation maintained and encouraged.

In technical development of design our Air Ministry must spend money by development contracts, as private enterprise will not be able to support the developments for some considerable time. This applies in particular to engine development. Attention should also be devoted to improvements in landing carriages and landing problems, also the reduction in fire risks.

In conclusion, it would appear that the future rate of development will depend almost entirely on the permissible rate of expenditure and on the efficiency of the outlays.

I have to express my regret that lack of time has prevented this paper from becoming more than a series of somewhat disconnected notes, but it is hoped that these may prove to record some of the more outstanding factors in one of the many great wonders of the world war.

I have to express my deep debt of gratitude to Lieutenant-Colonel Ogilvie and his partners, Messrs. Bristow, Pippard and Watts, for their invaluable assistance in the preparation of the paper, also to General Seeley, Under Secretary of State for Air, for permission to use the photographs of the different machines, and, finally, to the different aeronautical contractors for permission to use the photographs of the different machines.—"Engineering."

BOOK REVIEW.

NAVIGATION AND NAUTICAL ASTRONOMY, PROF. J. H. C. COFFIN, Eleventh Edition, revised and enlarged, by ELMER B. COLLINS, 259 pages. D. VAN NOSTRAND AND CO., $3.00 net.

Prof. Coffin's "Navigation and Nautical Astronomy" is an old friend. The new edition appears in the Van Nostrand binding uniformly with other nautical text books by the same publishers.

The treatment of the subject is practically the same as that of previous editions, but illustrations and problems conform to the new form of the Nautical Almanac and considerable space is given to the exposition of the use of lines of position; one chapter on the Sumner methods and another chapter on the Marc St. Hilaire and Aquino methods. The figures and explanations are clear and concise.

The paper is absorbent and does not lend itself to the underscoring and marginal references useful in a book to be used for frequent reference.—M. W. T.

SIMPLE RULES AND PROBLEMS IN NAVIGATION, 3d Edition, revised and corrected by BRADLEY JONES, 305 pages. CHARLES H. CUGLE. E. P. DUTTON CO., New York; price, $4.00 net. In this, the third edition of Mr. Cugle's book, many of the problems which appeared in earlier editions are worked out, while in addition there are examples for practice, with their answers. Several additional features have been embodied in the present edition. It is an excellent work, with theory subordinated to practical utility.

ASSOCIATION NOTES.

The following members and associates have joined the Society since the publication of the last number of the JOURNAL.

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MEMBERSHIP.

It is desired to increase our membership as much as possible, and the assistance of members and associates is solicited. It is especially requested that heads of Engineer Departments of vessels bring to the attention of younger officers the advantage to be gained by membership.

ADDRESSES.

Do not fail to keep the Secretary advised of your address at all times.